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Roanoke River PCB TMDL Development (Virginia)

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EXECUTIVE SUMMARY

Section 303(d) of the Clean Water Act and the U.S. Environmental Protection Agency's (EPA's) Water Quality Planning and Management Regulations (Title 40 of the *Code of Federal Regulations* [CFR] Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for impaired waterbodies. A TMDL establishes the amount of a pollutant that a waterbody can assimilate without exceeding its water quality standard for that pollutant. TMDLs provide the scientific basis for a state to establish water quality-based controls to reduce pollution from both point sources and nonpoint sources to restore and maintain the quality of the state's water resources.

A TMDL for a given pollutant and waterbody is composed of the sum of individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources and background levels. In addition, the TMDL must include an implicit or explicit margin of safety (MOS) to account for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. The TMDL components are illustrated using the following equation:

$$\mathrm{TMDL} = \sum WLAs + \sum LAs + MOS$$

The objective of the Roanoke River PCB TMDL study is to identify the sources of Polychlorinated Biphenyl (PCB) contamination in the watershed and determine the reductions in pollutant loadings necessary to achieve the applicable water quality standards. The TMDL study drainage area is approximately 2,379 square miles and includes two sections of the Roanoke River watershed—from its headwaters downstream to Niagra Dam (upper Roanoke) and from Leesville Dam downstream to its confluence with the Dan River [lower Roanoke (Staunton)]. The mainstem lengths of the upper and lower sections of the river are approximately 29 and 96 miles, respectively, and run through several Virginia counties, including Montgomery, Roanoke, Bedford, Franklin, Campbell, Pittsylvania, Charlotte, and Halifax.

The impairment listings for stream and reservoir segments in the study area are based on the historical fish tissue and sediment monitoring data record. This TMDL study was designed to address select PCB impairments included on Virginia's 1998 303(d) list. More recent monitoring studies have resulted in the listing of additional PCB-impaired stream and reservoir segments in the watershed, including updates on Virginia's 2008 303(d) list (Table ES-1) and a forthcoming violation listing (2010) of the public water supply use. The framework developed for these TMDLs does not include allocations for impaired segments outside of the study watersheds described above. It does include allocations for all stream segments in the study area, however, and if no other significant sources of PCBs are found, it can be assumed that these TMDLs will significantly improve the more recent PCB impairment listings, as well.

Table ES-1. 2008 303(d) PCB impaired segments

Waterbody	Impaired segment description	County/city	Miles/acres[b]	Initial listing[b]	2008 303(d) list ID
Roanoke River	Near Dixie Caverns – Mason Creek confluence	Roanoke, City of Salem, City of Roanoke	12.88 miles	2002	L12L-01-PCB
Roanoke River	Mason Creek confluence – Back Creek mouth	City of Salem, City of Roanoke	15.47 miles	1996	
Peters Creek	Peters Creek headwaters – Roanoke River confluence	Roanoke, City of Roanoke	7.17 miles	2004	
Tinker Creek	Deer Branch confluence – Roanoke River confluence	Roanoke, City of Roanoke	5.35 miles	2006	
Smith Mountain Lake[a]	Back Creek mouth – Smith Mountain Lake Dam (includes Blackwater arm up to Rt. 122 bridge)	Bedford, Franklin	17,157 acres	2002	
Blackwater	Maggodee Creek confluence	Franklin	11.43 miles	2006	

Waterbody	Impaired segment description	County/city	Miles/acres[b]	Initial listing[b]	2008 303(d) list ID
River[a]	– Blackwater River arm of Smith Mountain Lake				
Staunton (Roanoke) River	Leesville Dam – Pipeline crossing 5.4 miles downstream of Rt. 360 bridge	Charlotte, Halifax, Campbell, Pittsylvania	83.9 miles	1998	L19R-01-PCB
Staunton (Roanoke) River	Pipeline crossing 5.4 miles downstream of Rt. 360 bridge – Kerr Reservoir	Halifax, Charlotte	4.49 miles	1998	
Cub Creek	Rough Creek Rd. – Roanoke River confluence	Charlotte	14.25 miles	2008	
Little Otter River	West of Rt. 680 at Cobbs Mountain – mouth of the Little Otter River on the Big Otter River	Bedford	14.36 miles	2002	L26R-01-PCB

a. These segments are not included in the TMDL study area.
b. Source: http://www.deq.state.va.us/wqa/ir2008.html

TMDL reductions were calculated on the basis of meeting water quality targets in the upper and lower sections of the Roanoke (Staunton). Water quality targets were derived from Bioaccumulation Factors (BAF) and the Virginia Department of Environmental Quality (VADEQ) fish tissue criterion for total PCBs (tPCBs). BAFs allow for the back-calculation of a water concentration equivalent from a fish tissue concentration, in this case a threshold level of 54 parts per billion (ppb). Two endpoints were developed corresponding to the upper [390 picograms per liter (pg/L)] and lower (140 pg/L) sections of the Roanoke (Staunton) River basin on the basis of the available water quality and fish tissue monitoring data. The decision to evaluate the upper and lower sections separately was made because of the large reservoirs that separate them and the differences in the magnitude and composition of PCB contamination.

The TMDL endpoints have been developed to be protective of fish for human consumption and are more stringent than the 1,700 pg/L state criterion for human health. The human health criterion applies to waterbodies used for public water supply, in addition to all other surface waters. The TMDL endpoints, therefore, are more than adequate to protect the water supply use and address the forth coming violation listing (2010) of the public water supply use in the Roanoke River watershed.

A watershed modeling framework, consisting of the Loading Simulation Program C++ (LSPC) with sediment PCB modeling enhancements was developed, calibrated, and validated for the Roanoke River study watershed. LSPC is a dynamic watershed model that generates precipitation-driven simulation of time-variable flow and water quality. The LSPC model was configured to simulate PCBs in both the dissolved- and sediment-associated states. Sediment-associated PCB loading and in-stream transport, deposition, burial and resuspension processes, along with partitioning of PCBs in the water and sediment layer were incorporated into the model simulations. A summary of the TMDLs, LAs, and WLAs developed for streams in the Roanoke River watershed is presented in Table ES-2. Streams listed as impaired for PCBs on Virginia's 2008 303(d) list are identified by their associated list ID. A summary of the TMDLs, LAs, and WLAs by source category is presented in Table ES-3.

Table ES-2. Average annual tPCBs TMDLs for Roanoke River watershed streams

Stream	2008 303(d) list ID	Baseline (mg/yr)	WLA (mg/yr)	LA (mg/yr)	MOS (mg/yr)	TMDL (mg/yr)	% Reduction
Upper Roanoke River							
North Fork Roanoke River	Not listed	4,923.2	28.2	630.3	34.7	693.2	85.9
South Fork Roanoke River	Not listed	3,532.2	230.2	788.6	53.6	1,072.5	69.6
Masons Creek	Not listed	1,777.5	9.1	193.2	10.6	212.9	88.0
Peters Creek	L12L-01-PCB	1,742.6	65.4	31.2	5.1	101.7	94.2

Stream	2008 303(d) list ID	Baseline (mg/yr)	WLA (mg/yr)	LA (mg/yr)	MOS (mg/yr)	TMDL (mg/yr)	% Reduction
Upper Roanoke River							
Tinker Creek	L12L-01-PCB	16,593.6	103.9	3,414.2	185.2	3,703.2	77.7
Wolf Creek	Not listed	1,078.4	10.0	20.3	1.6	31.9	97.0
Unnamed Trib to Roanoke River	Not listed	59.4	0.5	1.3	0.1	1.9	96.8
Roanoke River	L12L-01-PCB	133,207.2	28,157.7	3,455.7	1,663.9	33,277.3	75.0
Upper Total		**162,914.1**	**28,605.0**	**8,534.8**	**1,954.7**	**39,094.5**	**76.0**
Lower Roanoke (Staunton) River							
Goose Creek	Not listed	5,400.9	0.1	1,812.4	95.4	1,907.9	64.7
Sycamore Creek	Not listed	93,226.4	1.4	186.3	9.9	197.6	99.8
Lynch Creek	Not listed	7,670.6	0.1	17.8	0.9	18.8	99.8
Reed Creek	Not listed	274.7	35.3	75.9	5.9	117.1	57.4
X-trib	Not listed	215,127.2	0.1	1.3	0.1	1.5	100.0
Unnamed Trib to Roanoke River	Not listed	12,848.6	0.1	19.1	1.0	20.2	99.8
Little Otter River	L26R-01-PCB	3,934.3	0.0	596.2	31.4	627.6	84.0
Big Otter River	Not listed	7,630.9	0.0	2,462.8	129.6	2,592.4	66.0
Straightstone Creek	Not listed	464.8	0.0	279.0	14.7	293.7	36.8
Seneca Creek	Not listed	692.9	0.0	400.8	21.1	421.9	39.1
Whipping Creek	Not listed	398.4	0.0	157.7	8.3	166.0	58.3
Falling River	Not listed	4,135.2	0.0	1,746.5	91.9	1,838.4	55.5
Childrey Creek	Not listed	390.2	0.0	201.3	10.6	211.9	45.7
Catawba Creek	Not listed	168.8	0.0	94.8	5.0	99.8	40.9
Turnip Creek	Not listed	376.2	0.0	272.6	14.3	286.9	23.7
Hunting Creek	Not listed	86.6	0.0	65.2	3.4	68.6	20.7
Cub Creek	L19R-01-PCB	1,376.7	0.0	997.4	52.5	1,049.9	23.7
Black Walnut Creek	Not listed	181.9	0.8	46.5	2.5	49.7	72.7
Roanoke Creek	Not listed	2,446.8	0.0	1,429.6	75.2	1,504.8	38.5
Difficult Creek	Not listed	823.2	0.0	462.1	24.3	486.5	40.9
Roanoke River	L19R-01-PCB	239,164.0	1,874.9	11,961.7	728.2	14,564.9	93.9
Lower Total		**596,819.2**	**1,912.7**	**23,287.1**	**1,326.3**	**26,526.1**	**95.6**

Table ES-3. Average annual tPCBs TMDLs for Roanoke River source categories

Source Category	Baseline (mg/yr)	TMDL (mg/yr)	% Reduction
Upper Roanoke River			
VPDES Dischargers	17,665.8	29,754.8	-68.4
Individual Industrial/General Permits	6,773.5	5.1	99.9
MS4	109,676.3	350.7	99.7
Contaminated Sites	7,853.5	1.1	100.0
Urban background (unknown sites)	12,082.4	120.4	99.0
Atmospheric Deposition	8,862.5	8,862.5	0.0
Total	**162,914.1**	**39,094.5**	**76.0**
Lower Roanoke (Staunton) River			
VPDES Dischargers	78,283.3	2,005.5	97.4
Individual Industrial/General Permits	388,007.2	7.9	100.0

MS4	11.7	0.1	99.3
Contaminated Sites	83,901.8	1.3	100.0
Urban background (unknown sites)	22,249.9	146.0	99.3
Atmospheric Deposition	24,365.4	24,365.4	0.0
Total	**596,819.2**	**26,526.1**	**95.6**

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1. INTRODUCTION AND BACKGROUND

Section 303(d) of the Clean Water Act and the U.S. Environmental Protection Agency's (EPA's) Water Quality Planning and Management Regulations (Title 40 of the *Code of Federal Regulations* [CFR] Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that are not supporting their designated uses even if pollutant sources have implemented technology-based controls. A TMDL establishes the maximum allowable pollutant load that a waterbody is able to assimilate and still achieve its designated use(s). The maximum allowable load is determined on the basis of the relationship between pollutant sources and in-stream water quality. A TMDL provides the scientific basis for a state to establish water quality-based controls to reduce pollution from both point sources and nonpoint sources to restore and maintain the quality of the state's water resources (USEPA 1991). The development of TMDLs requires an assessment of the waterbody's assimilative capacity, critical conditions, and other considerations.

Virginia's 2008 section 303(d) list classifies several waterbodies in the Roanoke River basin as impaired for Polychlorinated Biphenyls (PCB) from elevated PCB concentrations found in fish tissue and sediment samples. The Virginia Department of Environmental Quality (VADEQ) first collected monitoring data on PCB contamination in the basin in 1971. Regular fish tissue and sediment sampling for PCBs began in 1993, and a rotating basin monitoring schedule is ongoing as part of the Statewide Fish Tissue and Sediment monitoring program. The Virginia Department of Health (VDH) has issued fish consumption advisories for several sections of the Roanoke River and tributaries since 1998 on the basis of the fish tissue data collected by VADEQ.

Section 303(d) of the Clean Water Act requires states to develop TMDLs for waters that do not meet water quality standards. The objective of the Roanoke PCB TMDL study is to identify the sources of PCB contamination in the watershed and to determine the reductions required to achieve water quality standards for PCB impaired segments.

PCBs are a group of synthetic chemicals that consist of 209 individual compounds (known as congeners). Physically, they are either oily liquids or solids and are colorless to light yellow in color with no known smell or taste. PCBs made in the United States were marketed under the trade name Aroclor and most are identified by a four-digit numbering code in which the first two digits indicate that the parent molecule is a biphenyl. Each of the 209 possible PCB compounds consists of two sigma bonded, chlorine substituted phenyl groups. Individual PCB congeners differ in the number and position of the chlorine substituents. PCBs possess excellent dielectric and flame-resistant properties derived from their stable molecular structure. These same properties cause PCBs to accumulate in the fatty tissue of biota and bioaccumulate in the food chain (http://www.epa.gov/ttn/atw/hlthef/polychlo.html).

Although it is now illegal to manufacture, distribute, or use PCBs, before 1974 they were used in numerous products including, capacitors, transformers, plasticizers, surface coatings, inks, adhesives, pesticide extenders, paints, carbonless duplicating paper, etc. After 1974, PCB use was restricted to producing capacitors and transformers, and in 1979 the manufacture and use of PCBs was completely banned. Historically, PCBs had been introduced into the environment through discharges from point sources and through spills and releases. Although point source contributions are now controlled, facilities could be unknowingly discharging PCB loads as a result of historical contamination. Sites with PCB-contaminated soils can also act as precipitation-driven nonpoint sources. In addition, the widespread use of PCBs before their ban coupled with their stable molecular structure has caused a generalized distribution of the pollutant in air, soil, and water at background concentrations. Once in a waterbody, PCBs become associated with sediment particles. PCBs are very resistant to breakdown and thus remain in river and lake sediments for many years.

PCB concentrations in environmental media tend be very small, particularly in water due to its hydrophobic properties. Throughout the remainder of this document the units presented in Table 1-1 are used to describe PCB concentrations in fish tissue, sediments, and water.

Table 1-1. Common PCB concentration units and abbreviations

Media	Unit	Unit abbreviation	Parts-per description	Part-per abbreviation
Fish tissue, sediment	micrograms per kilogram	µg/kg	parts per billion	ppb
Water	micrograms per liter	µg/L	parts per billion	ppb
	picograms per liter	pg/L	parts per quadrillion	ppq

1.1. Watershed Description

The Roanoke River watershed drains a largely rural area of the coastal plain from the eastern edge of the Appalachian Mountains in southern Virginia, southeast across the Piedmont to the Albemarle Sound in northeastern North Carolina. The drainage area of the Roanoke River from its headwaters to the Dan River confluence is approximately 3,343 square miles with a length of approximately 227 miles, spanning three physiographic provinces along its course.

Moving southeast from the headwaters, these include the Valley and Ridge, Blue Ridge, and Piedmont. The river also crosses through several Virginia counties—including Montgomery, Roanoke, Franklin, Bedford, Pittsylvania, Campbell, Halifax, and Charlotte—in addition to two reservoirs, Smith Mountain Lake and Leesville Lake. The major tributaries to the Roanoke River, in downstream order, are the North and South Fork Roanoke River, Mason Creek, Peters Creek, Tinker Creek, Back Creek, Falling Creek, Blackwater River, Pigg River, Goose Creek, Sycamore Creek, Lynch Creek, Big Otter River, Seneca Creek, Falling River, Catawba Creek, Turnip Creek, Cub Creek, Roanoke Creek, and Difficult Creek.

The TMDL study area includes two sections of the Virginia portion of the watershed beginning at the river headwaters in the Blue Ridge Mountains downstream to Niagra Dam about 1.5 miles east of the city of Roanoke (upper Roanoke) and from Leesville Dam downstream to its confluence with the Dan River at approximately river mile 46 [lower Roanoke (Staunton)] (Figure 1-1). For the remainder of this document when the Roanoke River watershed/basin is discussed, it is in reference to the TMDL study portion of the watershed. Figure 1-2 presents the general location and major streams and lakes of the Roanoke River watershed and the TMDL study area.

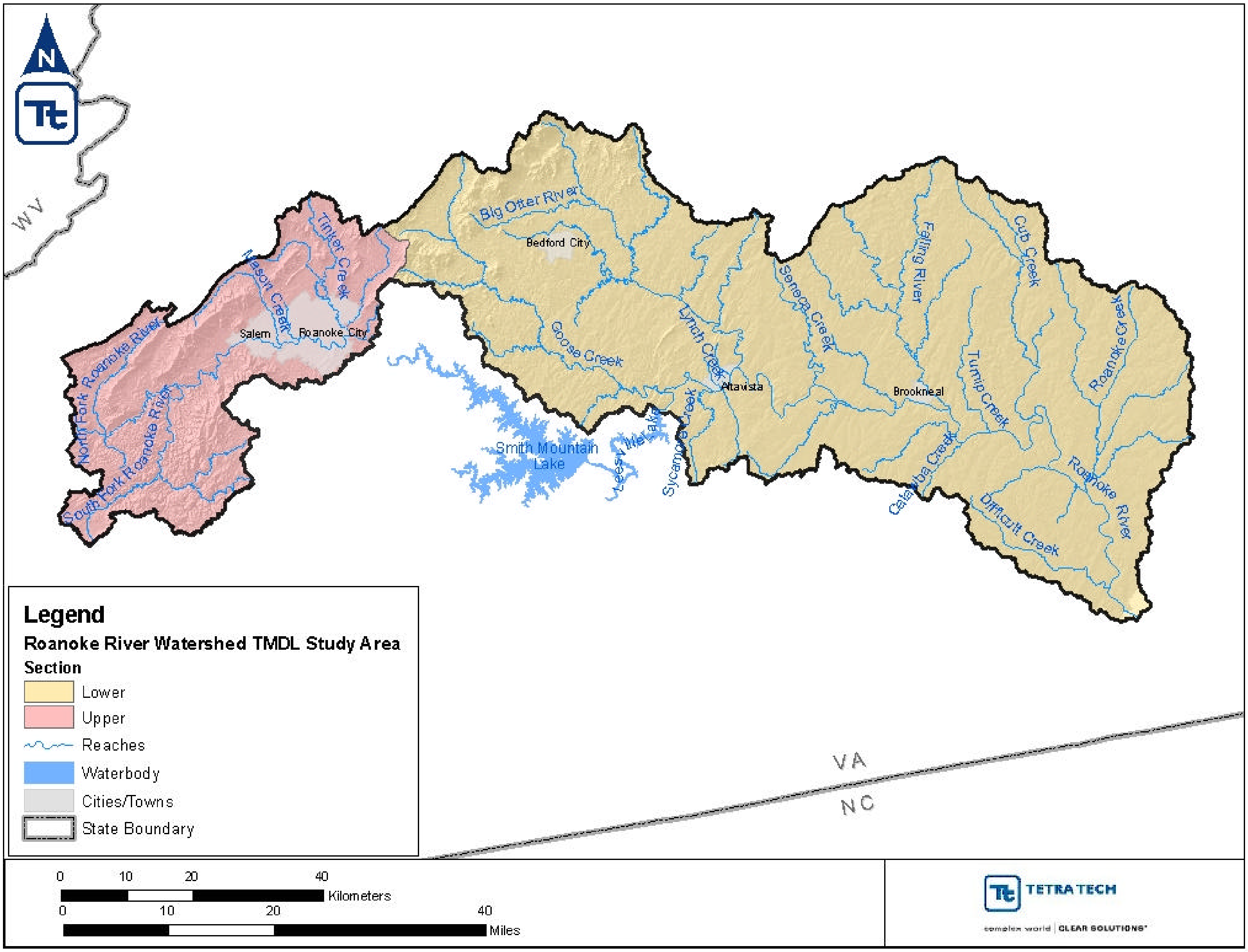

Figure 1-1. Roanoke River basin sections.

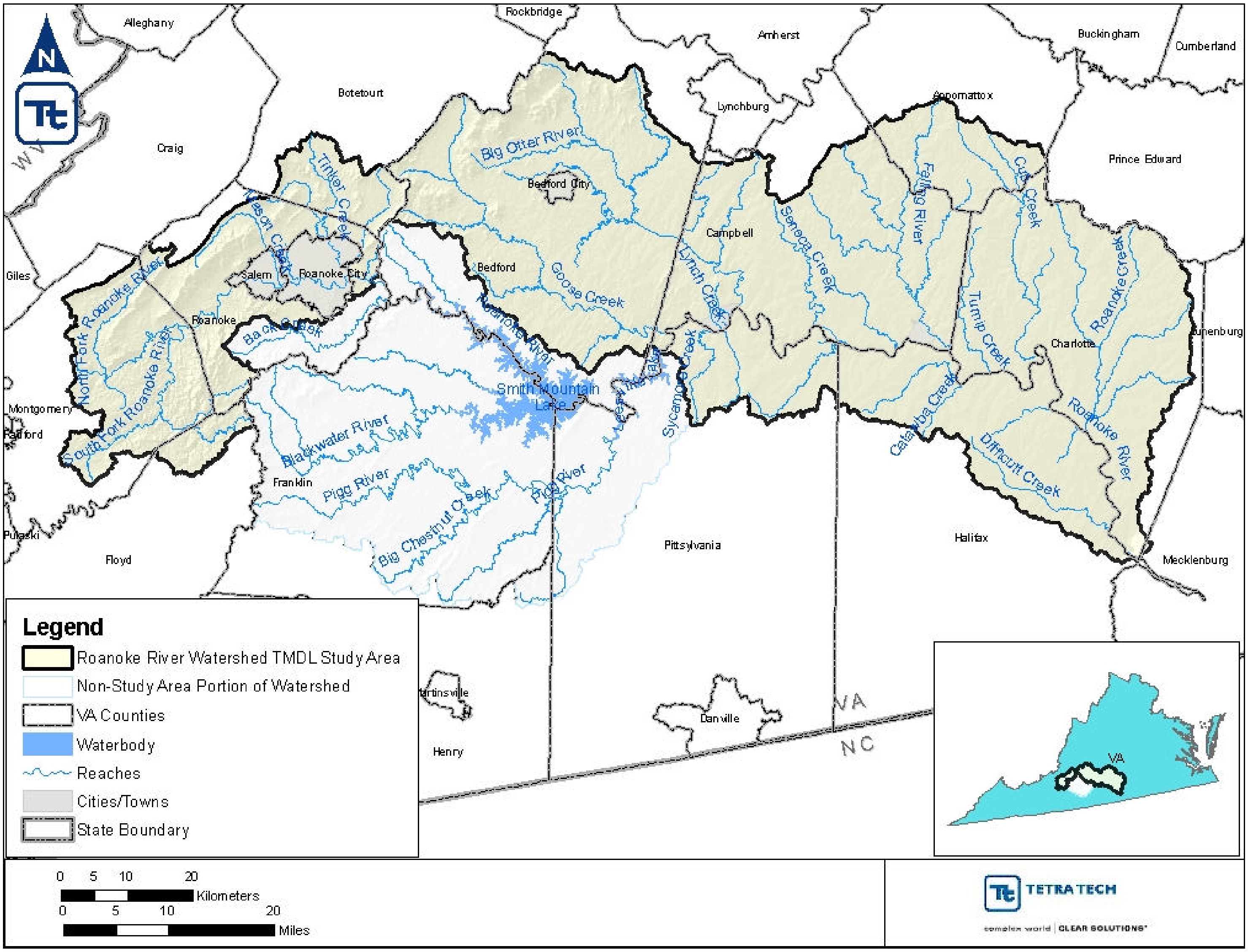

Figure 1-2. Location and major waterbodies of the Roanoke River basin.

1.2. Impaired Waterbodies

Impairment listings for stream and reservoir segments in the Roanoke basin are based on the historical monitoring data record. Investigation of PCB contamination in the watershed began in 1971 and continues today.

In 1971 the Virginia State Water Control Board (SWCB) conducted a study to determine the extent of pesticide contamination in Virginia waterbodies. As part of the study, elevated PCB concentrations were found in fish tissue samples collected from the Roanoke and Dan Rivers. These results were published in a 1973 report, *The Occurrence of Polychlorinated Biphenyls (PCBs) in the Roanoke and Dan Rivers, A Preliminary Report* (Wallmeyer 1973).

Between 1979 and 1991, the SWCB and EPA continued to monitor state waters, including fish tissue monitoring in the Roanoke River watershed. Fish samples collected in several segments of the river indicated a persistent presence of PCBs. In late 1992, the Virginia Department of Health (VDH) recommended collecting additional fish in the Roanoke basin to better characterize the extent of the contamination. SWCB conducted an extensive fish tissue study from February to August 1993 and issued a final report in June 1996 that concluded the occurrence of PCBs in resident fish species was widespread.

Under a Memorandum of Understanding between VADEQ and VDH, all fish tissue data generated by the Virginia Fish Tissue and Sediment Contaminants Monitoring Program are provided to VDH. VDH reviews the data and provides recommendations to VADEQ regarding the need for follow-up tissue studies and whether there is a potential unacceptable risk to human consumers. VDH uses a fish tissue contaminant screening level to determine potential risk. If fish tissue sample contaminant concentrations exceed the screening level, a fish consumption advisory is issued for the affected waterbodies. Where VDH issues a fishing ban or advisory, limiting consumption, the waterbody is designated as either partially or not supporting for fish consumption use based on the severity of the advisory. An advisory limiting fish consumption is considered partially supporting and an advisory prohibiting consumption is considered not supporting the fish consumption use (VADEQ n.d.).

The first PCB fish consumption advisory for basin waters was issued on July 24, 1998, for a segment of the Roanoke (Staunton) River beginning 29 miles below Leesville Dam and extending downstream to the Kerr Reservoir. The health advisory was issued on the basis of monitoring results from a 1998–1999 study that showed fish tissue PCB concentrations in the advisory area to be greater than the formerly applicable screening level of 600 parts per billion (ppb). On December 2, 1999, the fish consumption advisory was expanded to include the 29-mile segment upstream to the Leesville Dam.

On the basis of results of sampling studies conducted in 2000 and 2002, consumption advisories for the basin were expanded again on October 29, 2003 to include the segment of the Roanoke River from the Niagara Dam downstream to Smith Mountain Lake (Smith Mountain Lake segment). The most recent modifications (August 31, 2007) to the spatial extent of fish consumption advisories for the Roanoke River basin were a result of VDH adopting tiered screening levels that specify a *do not eat* PCB concentration threshold of 500 ppb and a limited consumption (fewer than two 8 ounce meals a month) PCB concentration range between 50 and 500 ppb and additional monitoring efforts by the state. Stream segments in the basin under fish consumption advisories include the following:

- Roanoke River (upper section): From the confluence of the North and South Forks of the Roanoke River (near the Lafayette gaging station) downstream to the Niagara dam, including tributaries Peters Creek upstream to the Route 460 bridge crossing, and Tinker Creek upstream to the confluence with Deer Branch (near Route 115).
- Roanoke River/Smith Mountain Lake: From the Niagara dam downstream to Smith Mountain Dam, including the Blackwater River arm of Smith Mountain Lake upstream to the Route 122 bridge.
- Roanoke (Staunton) River: From below Leesville Dam downstream to the confluence with Dan River including Cub Creek up to Rough Creek Road (State Route 695).

This TMDL study was designed to address select PCB impairments included on Virginia's 1998 303(d) list. The collection of additional fish tissue and sediment data since 1993 has resulted in a growing list of river and lake segments that are considered impaired for human health and aquatic life concerns, including updates on Virginia's 2008 303(d) list and a forthcoming violation listing (2010) of the public water supply use in the watershed. Table 1-2 and Figure 1-3 show the VADEQ 1998 and 2008 303(d) PCB impaired segments and the current VDH fish consumption advisory segments (as of August 31, 2007)

Table 1-2. 2008 303(d) PCB impaired segments and associated VDH fish consumption advisories

Waterbody	Impaired segment description	County/city	Miles/acres[b]	Initial listing[b]	2008 303(d) list ID	VDH advisory[c]
Roanoke River	Near Dixie Caverns – Mason Creek confluence	Roanoke, City of Salem, City of Roanoke	12.88 miles	2002	L12L-01-PCB	Roanoke River (upper section)
Roanoke River	Mason Creek confluence – Back Creek mouth	City of Salem, City of Roanoke	15.47 miles	1996		
Peters Creek	Peters Creek headwaters – Roanoke River confluence	Roanoke, City of Roanoke	7.17 miles	2004		
Tinker Creek	Deer Branch confluence – Roanoke River confluence	Roanoke, City of Roanoke	5.35 miles	2006		
Smith Mountain Lake[a]	Back Creek mouth – Smith Mountain Lake Dam (includes Blackwater arm up to Rt. 122 bridge)	Bedford, Franklin	17,157 acres	2002		Roanoke River/Smith Mountain Lake
Blackwater River[a]	Maggodee Creek confluence – Blackwater River arm of Smith Mountain Lake	Franklin	11.43 miles	2006		
Staunton (Roanoke) River	Leesville Dam – Pipeline crossing 5.4 miles downstream of Rt. 360 bridge	Charlotte, Halifax, Campbell, Pittsylvania	83.9 miles	1998	L19R-01-PCB	Roanoke (Staunton) River
Staunton (Roanoke) River	Pipeline crossing 5.4 miles downstream of Rt. 360 bridge – Kerr Reservoir	Halifax, Charlotte	4.49 miles	1998		
Cub Creek	Rough Creek Rd. – Roanoke River confluence	Charlotte	14.25 miles	2008		
Little Otter River	West of Rt. 680 at Cobbs Mountain – mouth of the Little Otter River on the Big Otter River	Bedford	14.36 miles	2002	L26R-01-PCB	None

a. These segments are not included in the TMDL study area.
b. Source: http://www.deq.state.va.us/wqa/ir2008.html
c. Source: http://www.vdh.state.va.us/epidemiology/DEE/publichealthtoxicology/advisories/RoanokeRiver.htm

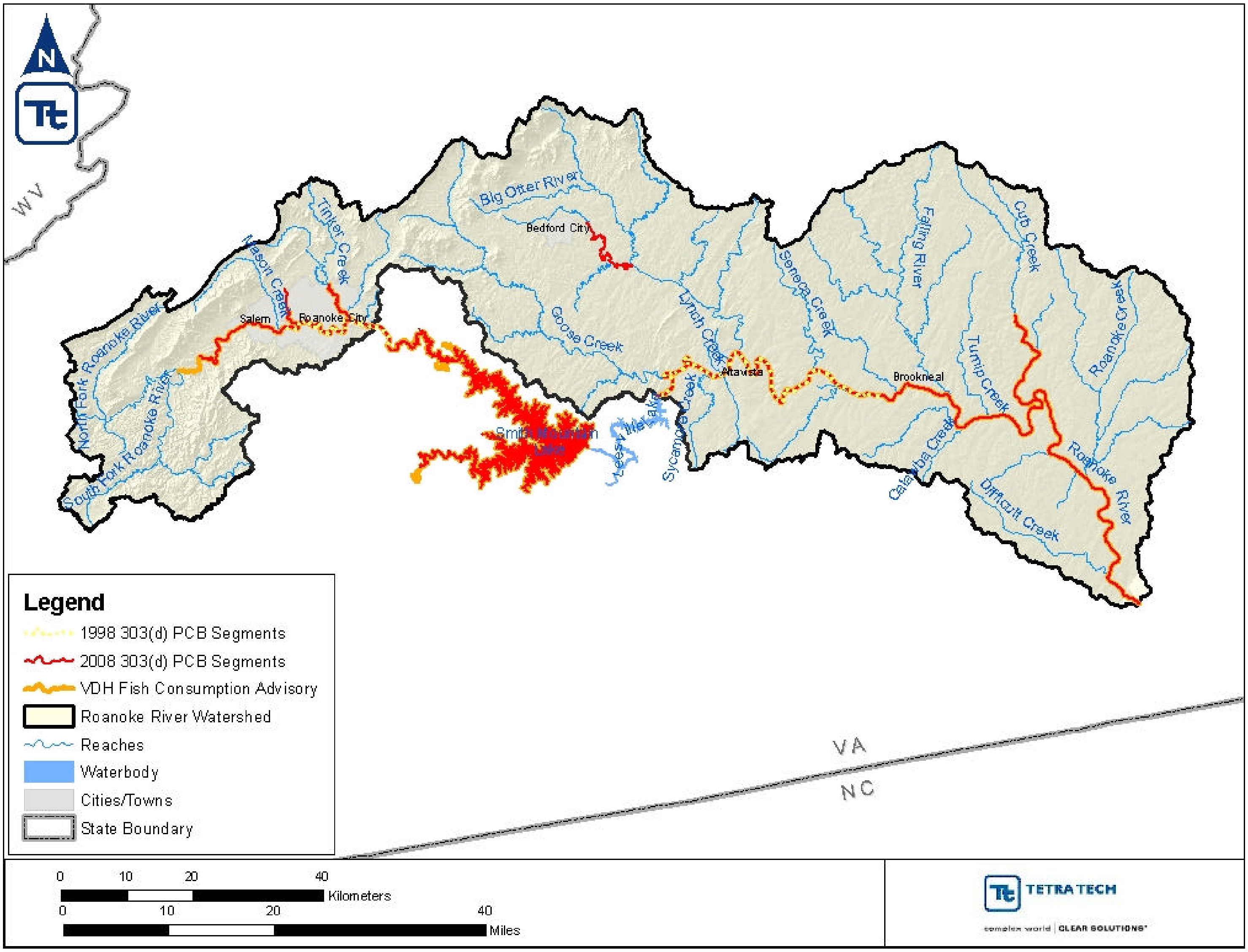

Figure 1-3. 1998 and 2008 303(d) PCB impaired segments and current fish consumption advisories.

1.3. Endangered Species Concerns

In addition to the human health concerns, there are concerns about the effects of PCB pollution on biota in the Roanoke River basin. The resident bald eagle population and the endangered Roanoke Logperch (*Percina rex*) have been identified by the Virginia Branch of the U.S. Fish and Wildlife Service (USFWS) as species that are potentially at risk from the effects of PCB contamination. The Roanoke Logperch is a federally endangered species that occurs only in the upper Roanoke drainage, Pigg River, Smith River, and larger tributaries. The Orangefin Madtom (*Nocturus gilberti*) is also found only locally and is listed as threatened in Virginia and as a species of special concern nationally.

1.4. Applicable Water Quality Standards

All surface waters in Virginia have the designated uses of contact recreation, propagation of fish and game, and production of edible and marketable natural resources (9 VAC 25-260-10). Virginia's water quality standards for the maintenance of designated uses include numeric Aroclor PCBs criteria for the protection of aquatic life and a total PCBs (tPCBs) criterion for the protection of human health (9 VAC-25-260-140.B). The state criteria are based on criteria developed by EPA as issued in its 1999 Final Rule: *Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants; States' Compliance—Revision of Polychlorinated Biphenyls (PCBs) Criteria* (USEPA 1999).

The 1999 final rule is an update to the human health criterion and a restatement of the aquatic life criteria both established as part of the National Toxics Rule (NTR) issued in 1992. The reassessment used revised PCB cancer study results and information on environmental processes, representative classes of environmental PCB mixtures, and different exposure pathways to develop a range of cancer slope factors—0.07 per milligram per kilogram per day (mg/kg-d) (lowest risk and persistence) to 2.0 per mg/kg-d (high risk and persistence)—that indicate the potency of a cancer-causing chemical. EPA determined that the major pathway of human exposure to PCBs is fish consumption and that bioaccumulated PCBs are the most toxic. As a result, the upper-bound cancer slope factor (2.0 per mg/kg-d) was selected to develop the 1999 human health criterion. The EPA criterion incorporates a bioconcentration factor (BCF) to account for the uptake and accumulation of PCBs in fish tissues from contaminated waters.

VADEQ has also developed a numeric criterion for tPCBs concentrations in fish tissue [54 micrograms per kilogram (µg/kg)]. Called a screening value (SV), it was developed using the same toxicological, exposure, and risk data used to develop the human health PCB criterion. The SV represents the fish tissue concentration that the Virginia water quality criterion is designed to protect and is considered by VADEQ to be its fish tissue concentration equivalent (VADEQ n.d.).

The hydrophobic properties of PCBs make them difficult to detect in water quality samples. As a result, VADEQ uses fish tissue monitoring data as a surrogate to determine whether a waterbody is attaining the human health PCB criterion. If a fish tissue composite sample exceeds the SV, the water is classified as threatened for fish consumption. Fish containing a contaminant at or below the screening value concentration are considered to pose minimal risk to the average consumer. Related VDH fish consumption advisory guidelines specify a *do not eat* PCB concentration threshold of 500 ppb and a limited consumption (not more than 2 meals a month) PCB concentration range between 50 and 500 ppb. Advisories limiting and prohibiting fish consumption define waters as not supporting the fish consumption use (VADEQ, 2008.).

VADEQ uses sediment PCB contamination data to assess the likelihood of an observed effect on aquatic life. Sediment monitoring data are compared to the Probable Effects Concentration (PEC) SV for sediment (MacDonald et al. 2000). This SV is considered to be protective of aquatic organisms exposed to PCBs in the sediment.

PCBs also have the potential to affect non-aquatic wildlife that consume contaminated fish. The USFWS conducted a study in the summer of 2003 to determine the acceptable concentration of PCBs in bald eagle eggs and forage fish (Kane 2004). The reported No Observed Adverse Effect Level (NOAEL) for bald eagles eggs was a tPCBs concentration of 40.0 µg/kg (wet weight). The World Health Organization (WHO) defines NOAEL "as the greatest concentration or amount of a chemical found by experiment or observation that causes no detectable adverse alteration of morphology, functional capacity, growth, development, or life span of the target." Considering potential bioaccumulation in the food chain, the acceptable tPCBs concentration in forage fish was calculated to be 4.52 µg/kg. This value represents the Total Dietary Concentration of PCBs in forage fish that would meet the above NOAEL. All PCB criteria and guidelines developed and adopted by regulatory agencies considered for use as the TMDL target are presented in Table 1-3.

Table 1-3. Applicable water quality, fish tissue, and sediment criteria/guidelines for PCBs

Agency	Criteria description	Pollutant	Aquatic life (ppb) Chronic	Human health (ppb) Chronic
Water Column				
Virginia Department of Environmental Quality (VADEQ)	State water quality criteria[a]	PCB-1260	0.014	
		PCB-1254	0.014	
		PCB-1248	0.014	
		PCB-1242	0.014	
		PCB-1232	0.014	
		PCB-1221	0.014	
		PCB-1016	0.014	
		tPCBs		0.0017
Fish Tissue				
VADEQ	State screening value[b]	tPCBs		54
Virginia Department of Health (VDH)	Limited consumption threshold[b]	tPCBs		50–500
	Do not eat threshold[b]	tPCBs		> 500
U.S. Fish and Wildlife Service (USFWS)	No Observed Adverse Effects Level (NOAEL)[c]	tPCBs	4.5	
Sediment				
VADEQ	State screening value based on Probable Effects Concentration[d]	tPCBs	676	

a. Source: Virginia State Code 9 VAC-25-260-140.B
b. Source: (VADEQ n.d)
c. Source: (Kane 2004)'
d. Source: (MacDonald et al. 2000)

1.5. Targeted Water Quality Goal

VADEQ assesses stream segments for PCB impairments through its fish tissue monitoring program. PCBs are hydrophobic and are thus difficult to detect in water quality samples. As a result, VADEQ uses fish tissue monitoring data as a surrogate to evaluate PCB water quality. The threshold fish tissue PCB concentration for designating a waterbody as impaired is based on toxicological, exposure, and risk data used to develop the numeric water column human health PCB criterion. The human health criterion includes a BCF component that takes into account the uptake and accumulation of PCBs in fish tissues from contaminated waters.

Development of the applicable human health criterion relied on guidance issued by EPA in 1980 (45 *Federal Register* [FR] 79347, November 28, 1980). However, in 1998 EPA proposed revisions to the methodology it uses to derive water quality criteria for human health (63 FR 43755, August 14, 1998) and issued revised guidance in a 2003 technical support document (USEPA 2003a). The revised methodology recommends the use of bioaccumulation factors (BAFs) in place of BCFs. Bioaccumulation considers multiple pathways of exposure to a contaminant (i.e., uptake from water, food, and sediments) as opposed to bioconcentration, which considers uptake from water only. This approach was also used in the development of PCB TMDLs for the tidal Potomac River (ICPRB, 2007).

The methods recommended by EPA were used to develop TMDL endpoints for the protection of human health specific to conditions in the Roanoke River basin employing analysis of the relationships between water column PCB concentrations and fish tissue concentrations. Water concentrations were related to fish tissue concentrations by calculating BAFs. BAFs allow for the back-calculation of a water concentration equivalent from a fish tissue concentration, in this case a threshold level of 54 ppb. BAFs were calculated for fish species for which requisite supporting data were available. A target species was selected from this group taking into account species of special concern to the basin stakeholders and relative BAF values with greater importance given to species with higher BAFs. A higher BAF results in a lower water concentration; therefore, the target species should be protective of all fish species with lower BAFs.

Watershed-section-specific BAF converted fish tissue concentrations are recommended for the TMDL target water quality criteria. Two endpoints were developed corresponding to the upper [390 picograms per liter (pg/L)] and lower (140 pg/L) sections of the Roanoke (Staunton) River basin on the basis of the available water quality and fish tissue monitoring data. The decision to evaluate the upper and lower sections separately was made because of the large reservoirs that separate them and the differences in the magnitude and composition of PCB contamination. The TMDL endpoints are more protective than the 1,700 pg/L state criterion for human health. The human health criterion applies to waterbodies used for public water supply, in addition to all other surface waters. The TMDL endpoints, therefore, are more than adequate to protect the water supply use and address the forth coming violation listing (2010) of the public water supply use in the Roanoke River watershed. The species used to derive the endpoints for the upper and lower sections of the Roanoke (Staunton) were carp and striped bass, respectively. The methods and results for calculating BAFs are described in Appendix A.

2. DATA INVENTORY AND ANALYSIS

TMDL development requires a complete review of existing data to characterize the extent of pollutant contamination and sources in the watershed. Data from numerous sources were used to characterize the watershed and water quality conditions, identify pollutant sources, and support the calculation of PCB TMDLs for the Roanoke River watershed. The development of PCB TMDLs in the Roanoke River watershed is subject to adaptive implementation and on-going source investigation whereby sources of PCB contamination are continuously being reviewed and updated based on the best available information. The following discussion of PCB sources, therefore, should be considered the most up-to-date information at the time of the development of these TMDLs, rather than a complete and final characterization.

2.1. General Data Inventory

The following inventories include physical and monitoring data used to characterize general conditions in the Roanoke River watershed as they relate to the development of PCB TMDLs within the framework of the technical approach. For discussion of the context in which each is incorporated into the technical approach, see Section 5.0 and Appendix G.

2.1.1. Land Use

Land use information for the Roanoke River basin is shown in Table 2-1 and Figure 2-1. Estimates of land use areas in the watershed were derived from the 2001 Multi-Resolution Land Characteristics (MRLC 2001) Consortium's National Land Cover Dataset (NLCD) developed by the U.S. Geological Survey (USGS). The NLCD was derived from satellite imagery taken circa 2001 and is the most current, detailed land use data available for the study area. Each 30-meter by 30-meter pixel in the satellite image is classified according to its reflective characteristics.

Both sections of the Roanoke (Staunton) watershed are predominantly forested with 64 and 63 percent of land area for the upper and lower classified as such, respectively. The cities of Salem and Roanoke are the largest population centers in the watershed and are in the upper segment. Consequently, though it has the smaller land area, the upper Roanoke has a larger area of urban land uses (49,431 acres). Further downstream, the watershed becomes largely pastoral with land cover in the lower segment 24 percent pasture or grassland compared with 11 percent in the upper segment. Cultivated crops and wetlands make up a small portion of the upper and lower watershed area at less than 2 percent each in both sections.

Table 2-1. 2001 NLCD land use distribution in the Roanoke River basin

Detailed land use description	Group land use description	Upper land use area (acre)			Lower land use area (acre)		
		Detailed	Grouped	Grouped %	Detailed	Grouped	Grouped %
Open Water	Water/Wetland	1,100			6,051		
Woody Wetlands		27			21,005		
Herbaceous Wetlands		60	1,187	0.3	487	27,543	1.9
Pasture/Hay	Pasture	36,823			308,084		
Grassland		15	36,838	11.3	26,726	334,810	24.4
Row Crops	Cropland	2,048	2,048	0.6	14,125	14,125	1.1
Deciduous Forest	Forest	189,706			523,242		
Evergreen Forest		14,318			149,118		
Mixed Forest		5,199			51,915		
Shrub/Scrub		26	209,250	64.1	25,246	749,521	63.0
Barren Land	Other	99			2,932		
Developed, Open Space		27,482	27,582	8.5	49,233	52,165	5.2
Developed, Low Intensity	Developed	34,303			15,263		
Developed, Medium Intensity		11,050			2,146		
Developed, High Intensity		4,078	49,431	15.1	731	18,140	4.4
Total		*326,336*		*100.0*	*1,196,304*		*100.0*

Source: (MRLC 2001)

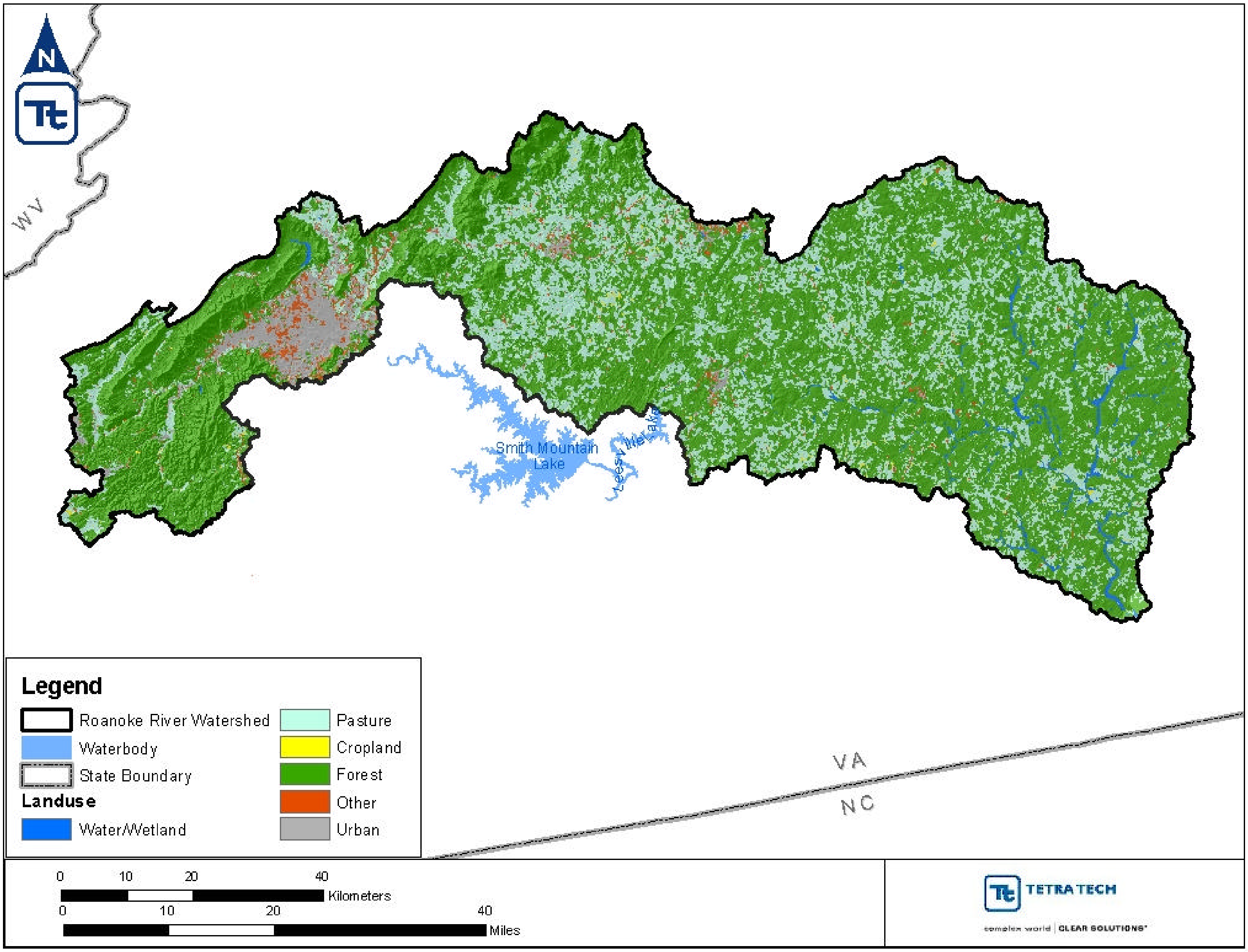

Figure 2-1. Land use in the Roanoke River basin (MRLC 2001).

2.1.2. Soils

Soils data developed by the Natural Resources Conservation Service (NRCS) were used to characterize soils in the Roanoke River basin. General soils data are available as map unit delineations for the United States provided as part of the State Soil Geographic (STATSGO) database. The geographic information system (GIS) data coverages provide accurate locations for the soil map units at a scale of 1:250,000 (USDA 1995). A map unit is composed of several soil series having similar properties. Identification fields in the GIS coverage can be linked to a database that provides information on chemical and physical soil characteristics. Because multiple soil series characterize each soil map unit, a weighted sum of soil series parameters was calculated to describe the general properties of interest for each soil map unit.

Hydrologic Soil Group

Hydrologic soil classifications group soils by similar infiltration and runoff characteristics during periods of prolonged wetting. Typically, clay soils that are poorly drained have lower infiltration rates, while well-drained sandy soils have the greatest infiltration rates. NRCS has defined four hydrologic groups for soils (Table 2-2) (USDA 1993). Figure 2-2 shows the distribution of hydrologic soil groups in the Roanoke River basin.

Table 2-2. NRCS hydrologic soil groups

Hydrologic soils group	Description
A	Soils with high infiltration rates. Usually deep, well drained sands or gravels. Little runoff
B	Soils with moderate infiltration rates. Usually moderately deep, moderately well drained soils.
C	Soils with slow infiltration rates. Soils with finer textures and slow water movement
D	Soils with very slow infiltration rates. Soils with high clay content and poor drainage. High amounts of runoff.

Source: (USDA 1993)

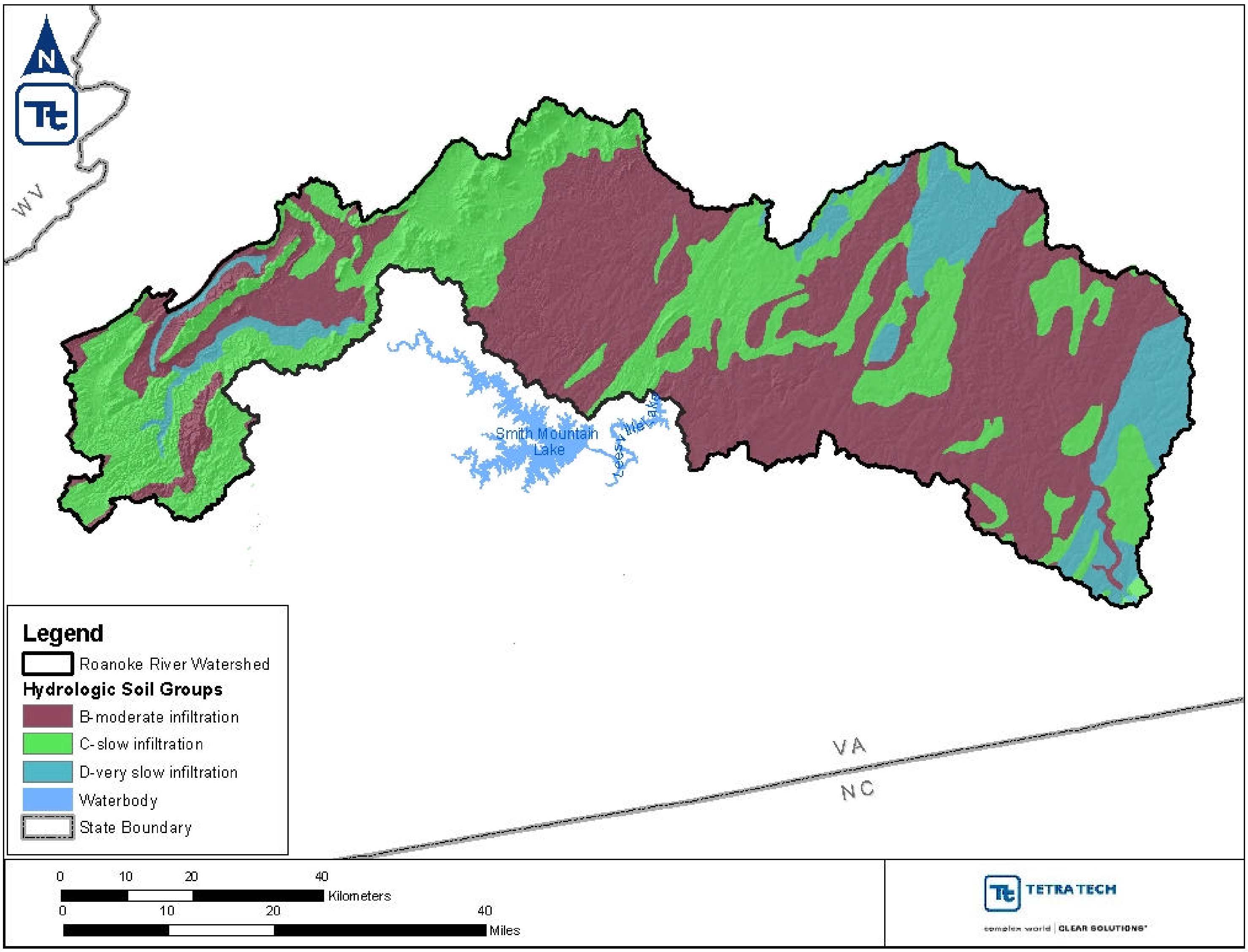

Figure 2-2. Hydrologic soil groups in the Roanoke River basin (USDA 1995).

2.1.3. Topography

Stream types, precipitation, and soil types can vary dramatically by elevation. The National Elevation Dataset (NED), developed by the USGS, was used to characterize the topography in the Roanoke River basin (USGS 2009). The NED consists of 30-meter grid resolution elevation data for the conterminous

United States. Topography in the basin varies from the steep slopes and valleys in the Valley and Ridge Province to gently sloping terrain in the Piedmont Province. Figure 2-3 shows the elevation distribution in the watershed. Elevation ranges from 1,282 meters (4,206 feet) above mean sea level (AMSL) in the headwaters of Big Otter River to 85 meters (80 feet) AMSL at the Dan River confluence.

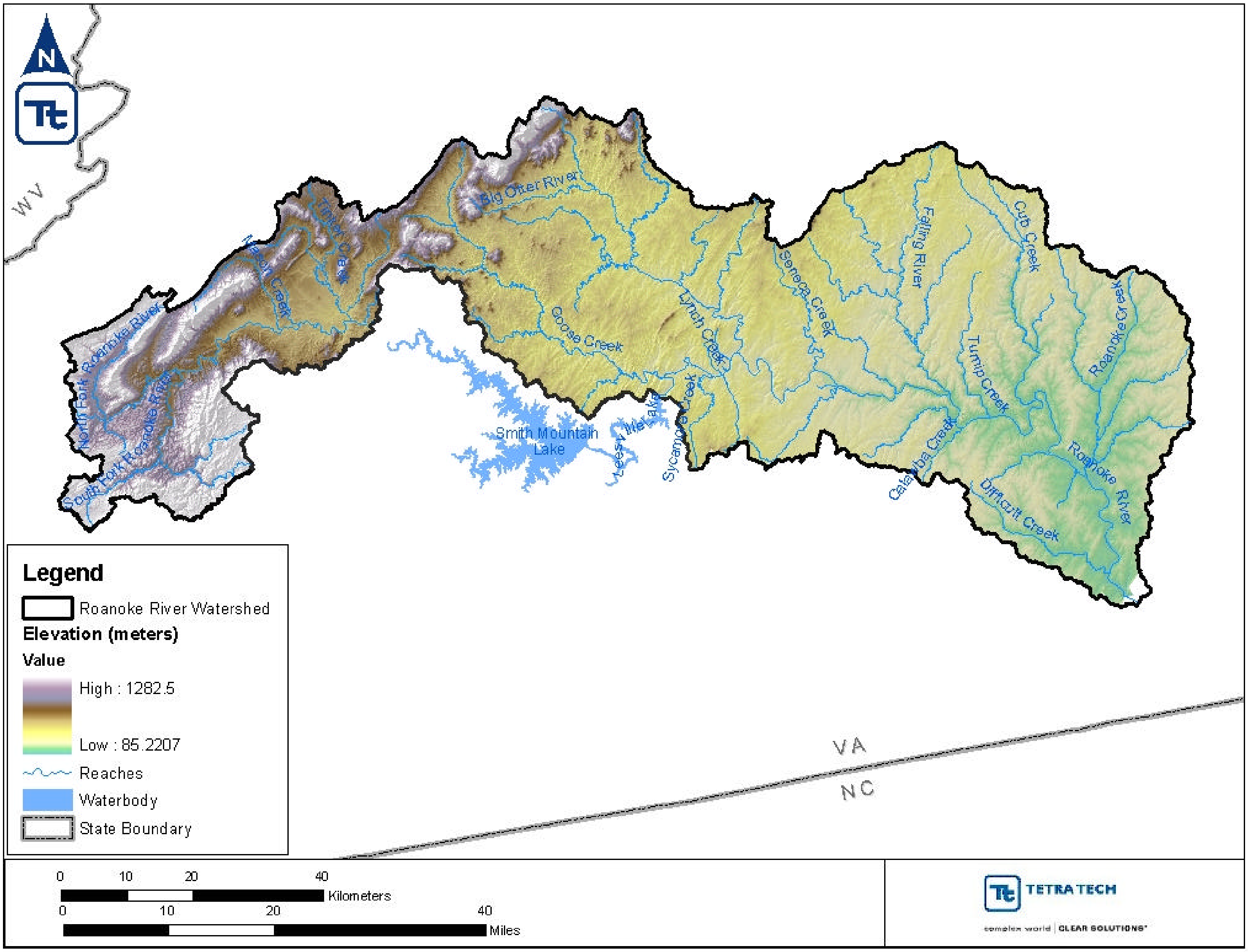

Figure 2-3. Elevation in the Roanoke River basin (USGS 2009).

2.1.4. USGS Stream Flow Gages

USGS flow gage data were compiled to characterize the hydrology of the Roanoke River and its major tributaries. Data of interest included daily average continuous stream flow data, which were obtained through the USGS National Water Information System. Stream gages with data available for the watershed are presented in Table 2-3 with associated statistics for period of record and percent completeness. Figure 2-3 presents the locations of gages in the watershed.

Table 2-3. USGS continuous stream flow gages in the Roanoke River basin

Site ID	Station name	Drainage area (square miles)	Period of record	% Complete
02053800	South Fork Roanoke River near Shawsville, VA	109	1/1/1980-9/9/2006	100.0%
02054500	Roanoke River at Lafayette, VA	254	1/1/1980–9/9/2006	100.0%
02054510	Roanoke River near Wabun, VA	270	1/1/1995–9/9/1999	100.0%
02054530	Roanoke River at Glenvar, VA	281	1/1/1992–9/9/2006	99.9%
02055000	Roanoke River at Roanoke, VA	384	1/1/1980–9/9/2006	100.0%
02055100	Tinker Creek near Daleville, VA	11.7	1/1/1980–9/9/2006	99.9%
02056000	Roanoke River at Niagra, VA	509	1/1/1980–9/9/2006	100.0%
02059500	Goose Creek near Huddleston, VA	188	1/1/1980–9/9/2006	99.9%
02060500	Roanoke River at Altavista, VA	1,782	1/1/1980–9/9/2006	100.0%
02061500	Big Otter River near Evington, VA	315	1/1/1980–9/9/2006	99.9%
02062500	Roanoke (Staunton) River at Brookneal, VA	2,404	1/1/1980–9/9/2006	99.3%
02064000	Falling River near Naruna, VA	165	1/1/1980–9/9/2006	100.0%
02065500	Cub Creek at Phenix, VA	97.6	1/1/1980–9/9/2006	100.0%
02066000	Roanoke (Staunton) River at Randolph, VA	2,966	1/1/1980–9/9/2006	99.9%

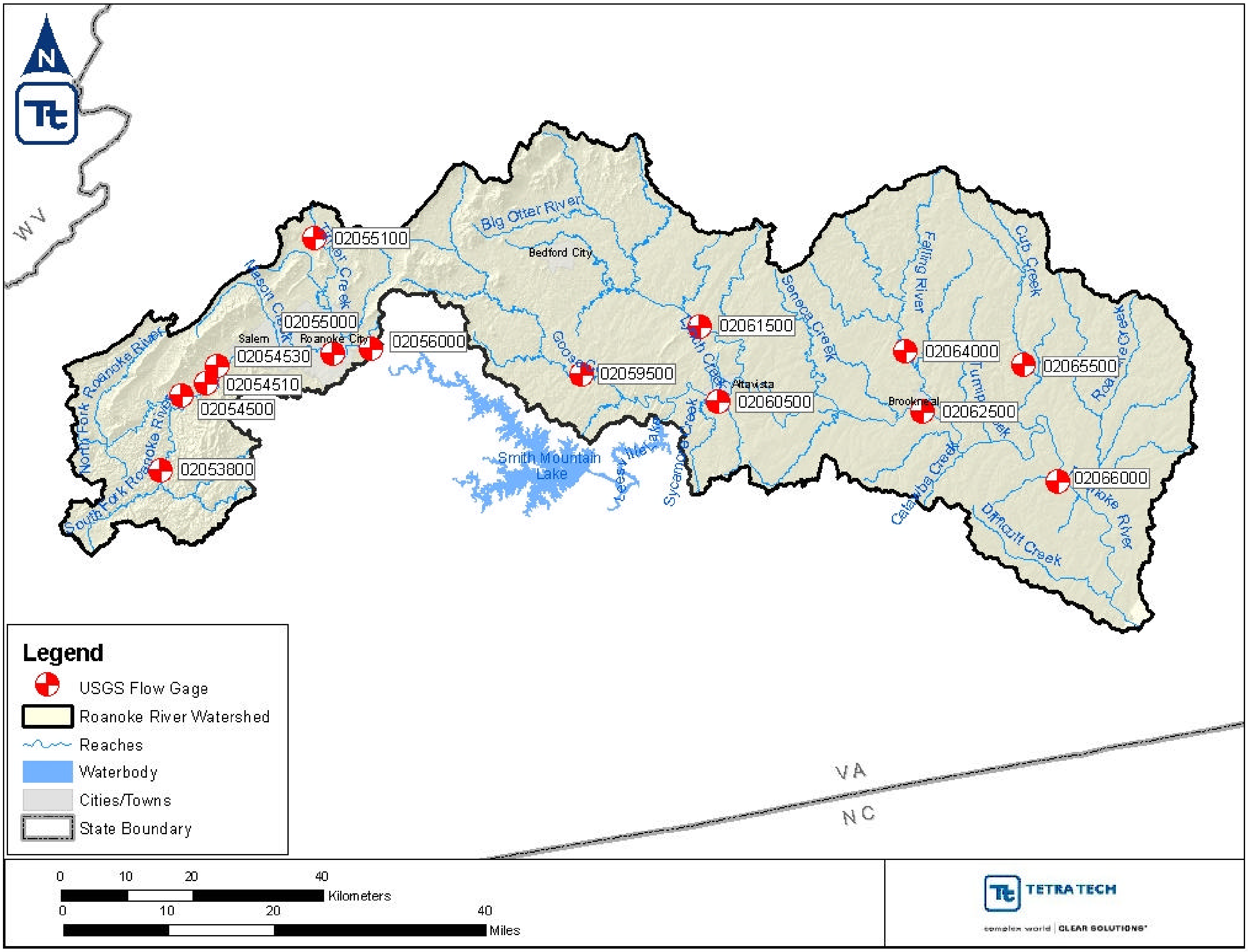

Figure 2-4. USGS continuous stream flow gages in the Roanoke River basin.

2.1.5. TSS Monitoring

VADEQ conducted total suspended solids (TSS) monitoring for waters in the Roanoke River watershed as part of VADEQ's Ambient Water Quality Monitoring Program (AWQMP) and various special studies. The primary function of the AWQMP is to provide data for the National Water Quality Inventory Report on the quality of state waters as required by section 305(b) of the Clean Water Act. From 1990 to 2008, 64 water quality stations were sampled for TSS in the Roanoke River basin (Figure 2-5). For a complete list of these stations and associated location descriptions and statistics, see Table B-4 in Appendix B. Note that the monitoring station IDs in Figure 2-5 follow a standard format. The first three letters identify the stream on which the station is located, followed by five digits specifying the river mile. A river mile identifies the station's distance from the mouth of the river measured along the route of the river.

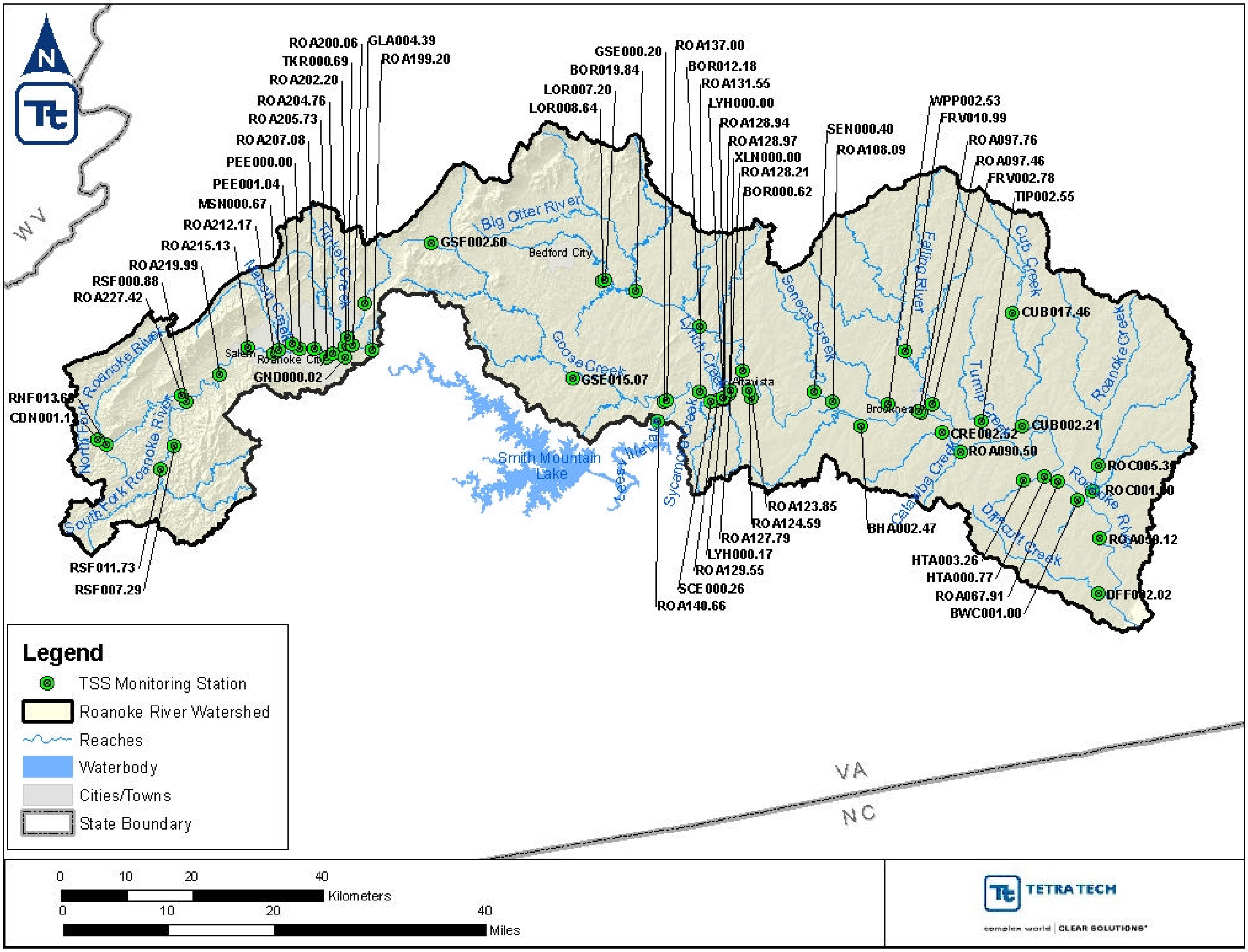

Figure 2-5. TSS monitoring stations in the Roanoke River basin.

2.2. PCB Monitoring Data Inventory

The following PCB data summary was developed on the basis of the fish tissue, sediment, and water quality monitoring data reviewed as part of TMDL development. Fish tissue PCB data collected in 1971 and presented in the 1973 report, *The Occurrence of Polychlorinated Biphenyls in the Roanoke and Dan Rivers—A Preliminary Report* (Wallmeyer 1973), are not included because of significant advances in analytical detection sensitivity since the 1970s. Ambient water quality monitoring conducted before 2006, though discussed, has also been excluded from the proceeding analysis because of concerns of background contamination and unknown analytical methods. Table 2-4 presents the available sources of PCB monitoring data for the Roanoke River basin.

To support TMDL development, additional PCB data were collected in fall 2005 through spring 2008 at selected monitoring locations in the watershed. Sampling included the use of semi-permeable membrane devices (SPMDs) and a high-resolution, low-detection level analysis method (1668A) to assess water column PCB concentrations, as well as effluent concentrations at selected facility outfalls. Details of the development of the 2005 special study are presented in the October 2005 *Sampling and Analysis Plan, Roanoke River Basin PCB TMDL Development (Virginia)* (Tetra Tech 2005).

Note that the monitoring station IDs in Figures 2-6 through 2-8 presented in Section 2.2.1 follow a standard format. The first three letters identify the stream on which the station is located, followed by five digits specifying the river mile. A river mile identifies the station's distance from the mouth of the river measured along the route of the river.

Table 2-4. PCB data sources for the Roanoke River basin

Data set	VADEQ data source	Period of record	Sample count
PCB water column data	Parameter specific data set submitted by VADEQ	1978–1996	40
PCB fish tissue data	Online data post	1993–2006	678
PCB sediment data	Online data post	1996–2008	127
Semi-permeable Membrane Devices	TMDL special study	2006	21
High Resolution Low Detection Level Analysis Method (1668a)	TMDL special study	2005–2008	59 water column, 12 effluent samples

2.2.1. PCB Monitoring Locations

VADEQ collects fish tissue and sediment samples as part of the Virginia Fish Tissue and Sediment Contaminants Monitoring Program. Under the program, data are collected to assess the human health risks for individuals who might consume fish from state waters and to identify impaired aquatic ecosystems. The sampling program is charged with monitoring every major watershed in Virginia at least once within a 2–3 year cycling period. In addition to *routine* samples taken as a part of the standard cycling period, monitoring at study sites can take place as part of the special Virginia Environmental Emergency Response Fund or in the case of a special request approved by VADEQ (VADEQ 2004).

From 1993 to 2008, 40 fish tissue and 108 sediment stations were sampled in the Roanoke River basin. Of these, 24 fish tissue and 56 sediment stations are on the Roanoke River mainstem (including the North and South Forks) with the remainder on tributaries. Fish tissue station locations are presented in Figure 2-6. Sediment station locations are presented in Figure 2-7a and 2-7b. Appendix B presents a summary of available fish tissue and sediment data, as well as station descriptions.

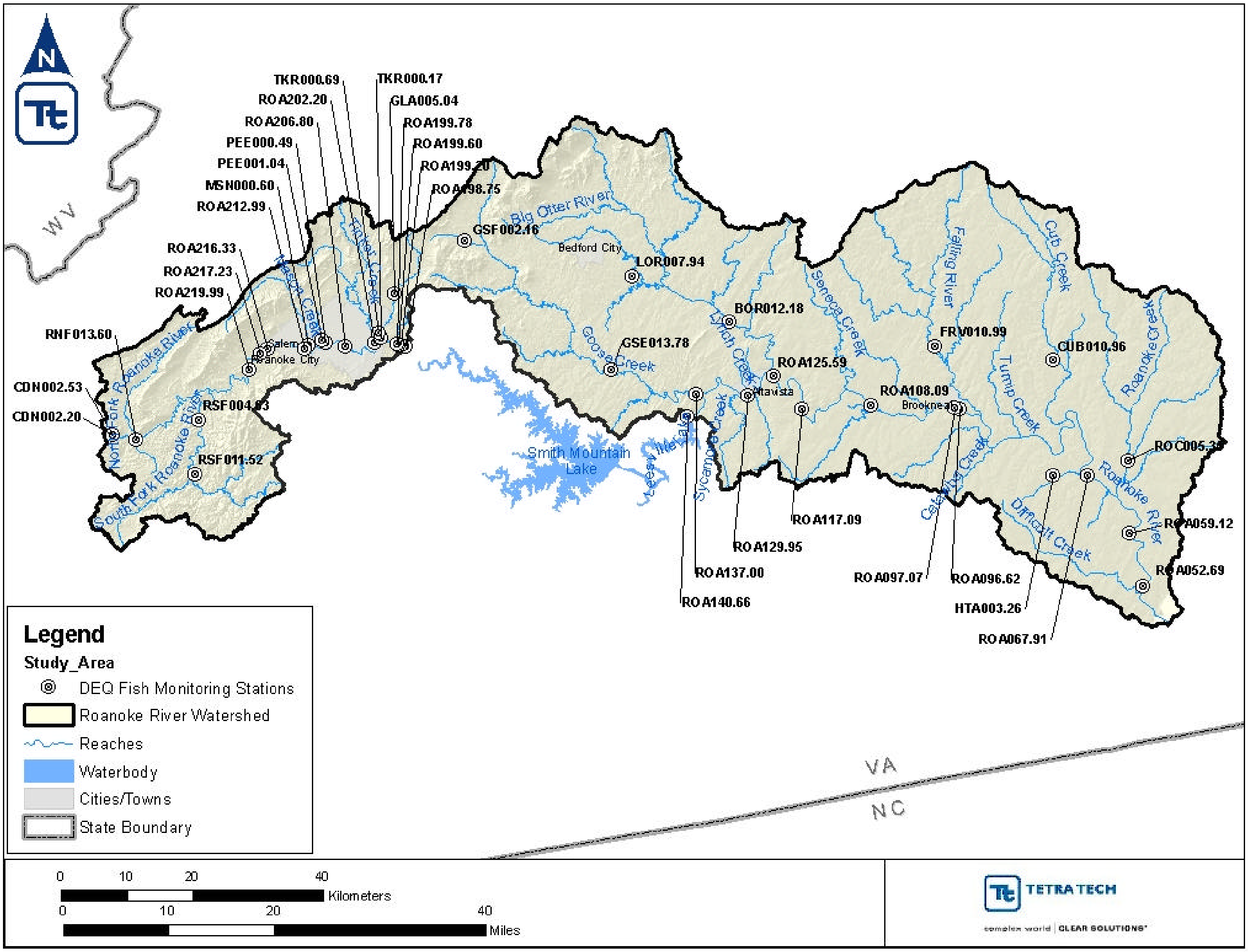

Figure 2-6. VADEQ fish tissue monitoring stations.

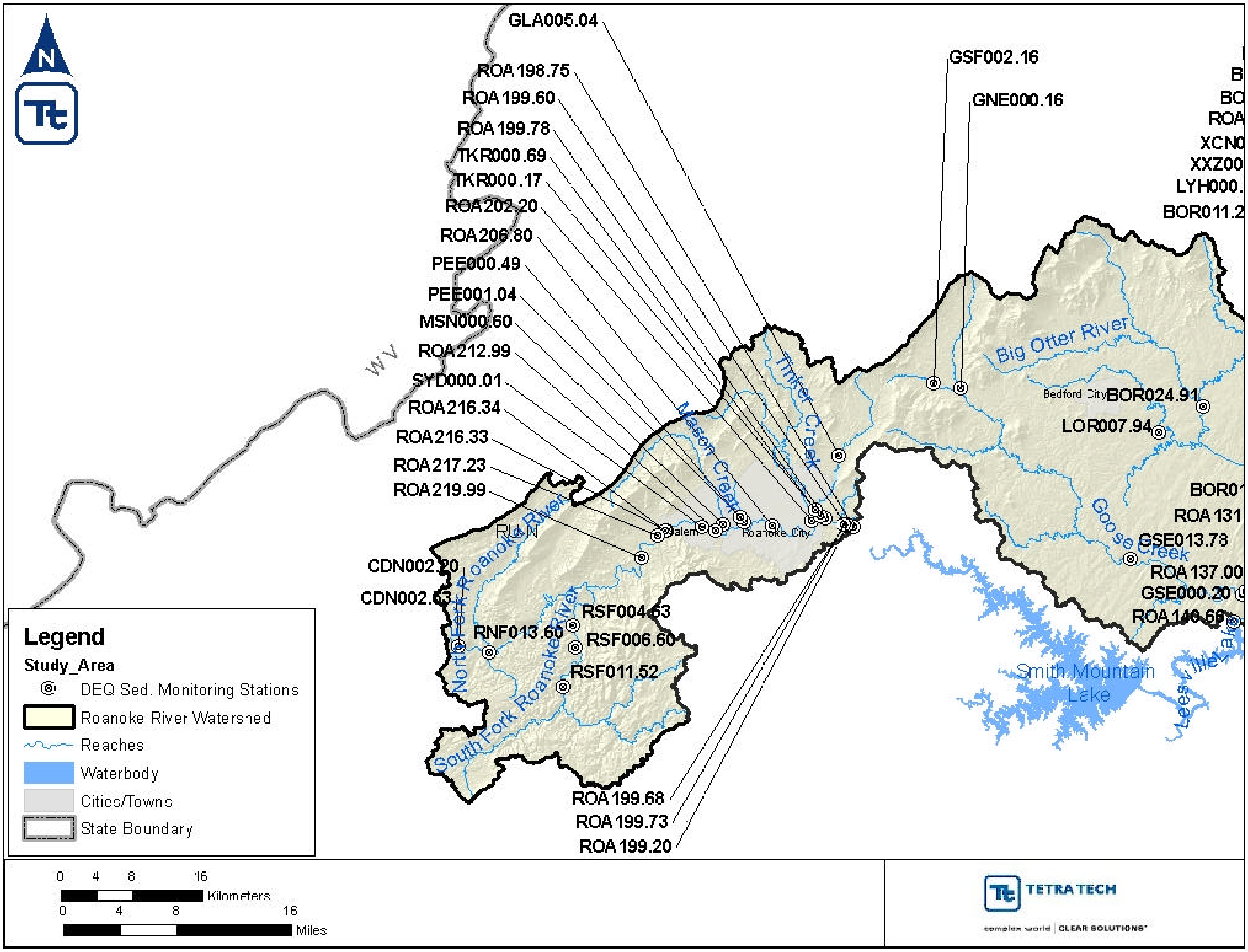

Figure 2-7a. VADEQ sediment monitoring stations-upper Roanoke.

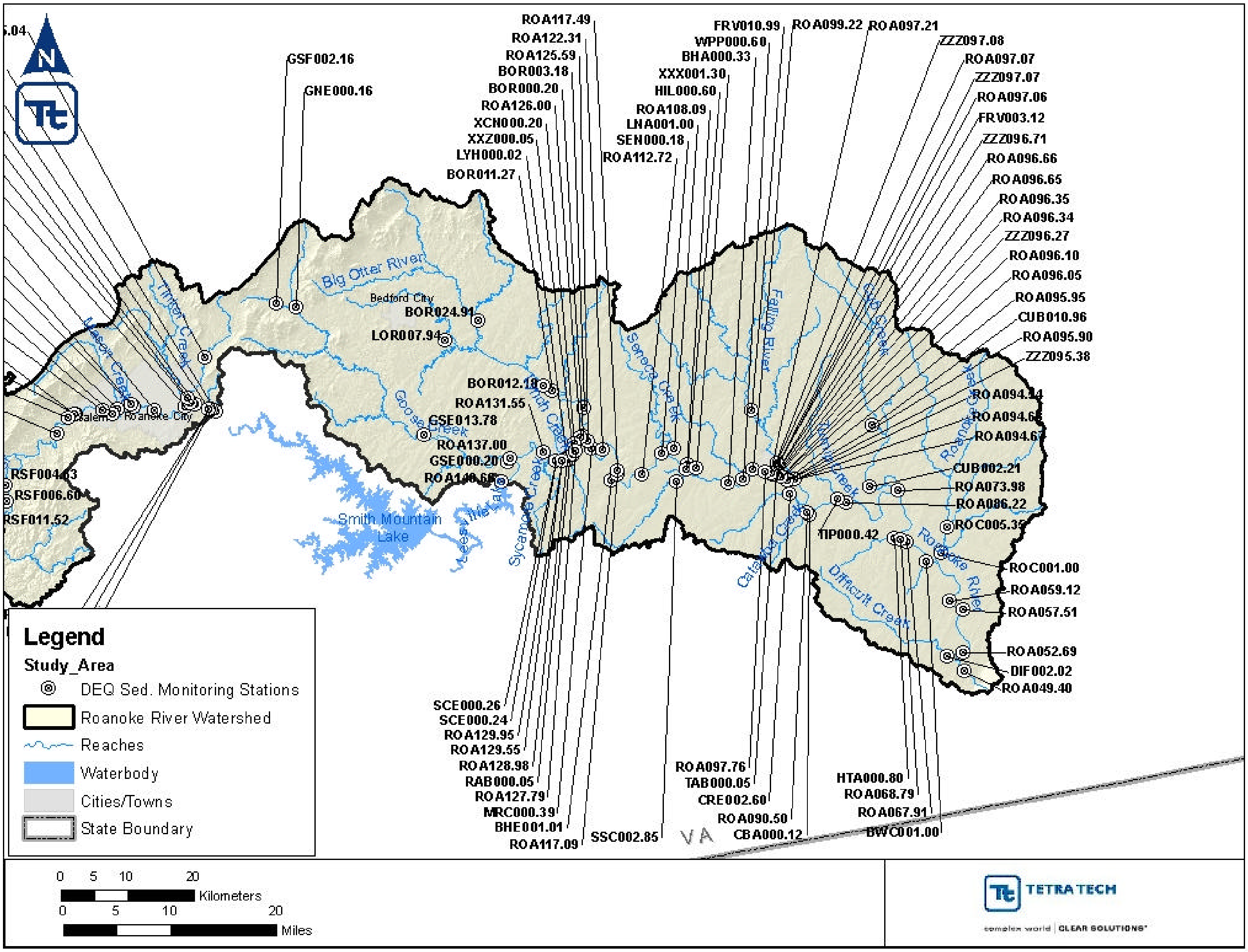

Figure 2-7b. VADEQ sediment monitoring stations-lower Roanoke (Staunton).

VADEQ collects water column samples as part of its AWQMP. The primary function of the AWQMP is to provide data for the National Water Quality Inventory Report on the quality of state waters as required by section 305(b) of the Clean Water Act. From 1978 to 1996, 21 water quality stations were sampled for PCBs in the Roanoke River basin. The analytical methods used to process samples during this period routinely failed to detect measurable concentrations of PCBs in contaminated waters because of their hydrophobic properties. A single record from the data set reported PCB concentrations above the detection limit. Because of the age and uncertainty associated with these data, they have been excluded from the analysis that follows.

A special study was conducted by VADEQ in the Roanoke River basin in fall 2005 through spring 2008 that included water column PCB monitoring. The special study was designed, in part, to augment the existing water quality record in support of TMDL development. Water quality samples were collected at low-flow and high-flow conditions at 29 monitoring locations throughout the watershed. The special study results were processed using a high-resolution, low-detection level analysis method (1668A) specifically to account for the hydrophobic properties of PCBs. The special study water quality station locations are shown in Figure 2-8, and the data summary and station descriptions are provided in Table B-3 in Appendix B.

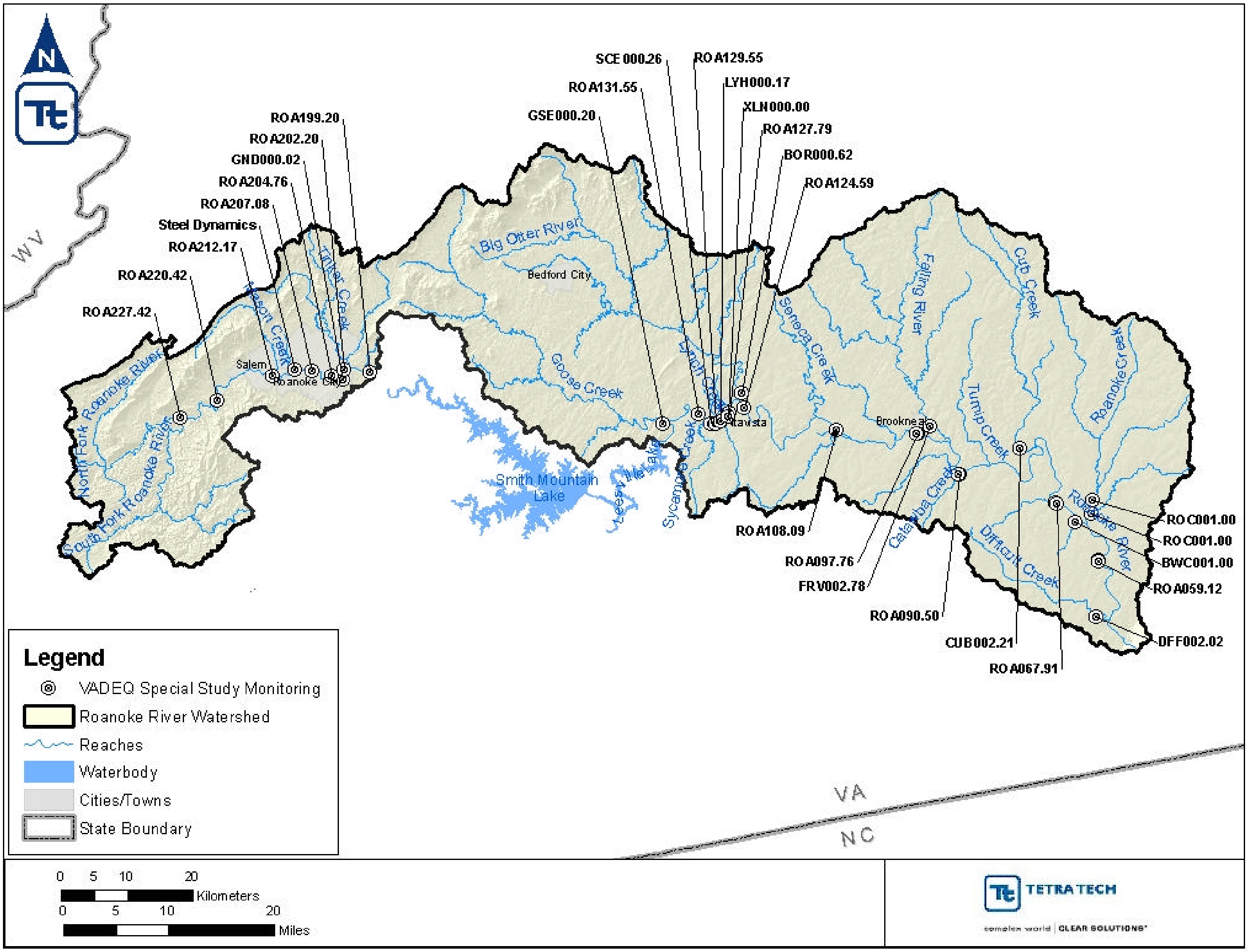

Figure 2-8. Special study water quality monitoring stations.

2.2.2. Fish Tissue and Sediment PCB Results

VADEQ collects and analyzes fish tissue and sediment samples under the Fish Tissue and Sediment Monitoring Program. Data collected in the Roanoke River basin were compiled and summarized to help identify spatial trends and help identify potential PCBs sources in the watershed. Note that the mobility and seasonal migration patterns of various fish species can limit the conclusions that can be drawn from analyzing the spatial distribution of PCB concentrations in fish tissue samples. The location of dams, tributaries, and other physical characteristics can influence the PCB signature in fish tissue samples. These and other factors are also considered in the analysis of sediment PCB data.

PCBs typically adsorb to sediment particles, which are transported into streams and rivers through erosion, stormwater runoff, and other processes. Although the in-stream transport of sediment can cause uncertainty as to the source of contamination, its movement is relatively predictable, and the presence of PCBs can be assumed to be an indicator of an upstream source (active or legacy). In lieu of reliable water column monitoring results, areas with high fish tissue and sediment concentrations provide the strongest evidence of local PCB contamination problems. The Roanoke River basin was divided into upper and lower sections for data analysis purposes as described in Section 1.1 and presented in Figure 1-2. Data analysis observations are noted at the end of this section.

Fish Tissue PCB Results

Figures 2-9 through 2-12 present the 25th–75th percentile, range, average, and median tPCBs concentrations of fish species collected at fish tissue monitoring stations summarized for the entire period of record (fish species abbreviations are presented in Table 2-5). The VADEQ fish tissue screening value (54 µg/L) is also provided to give a point of comparison between the figures. Monitoring results are grouped by watershed section and have been broken out into mainstem (North and South Fork Roanoke and Roanoke rivers) and tributary stations. Stations are presented in an upstream–downstream progression for spatial analysis purposes according to the station river-mile code. Data summaries and location descriptions for fish tissue monitoring stations are presented in Appendix B.

Station IDs have been condensed for Figures 2-9 through 2-12 for the purpose of presentation. Station IDs differ from those presented in the map of fish tissue monitoring station locations (Figure 2-6) as follows:

- River miles are expressed at the highest significant digit, not as a standard five digits (eg. 56.1 vs. 056.10).
- With the exception of stations on the North and South Forks of the Roanoke (NF and SF), mainstem Roanoke monitoring stations are presented as the river mile only. The North and South Fork stations IDs begin with an NF and SF, respectively, followed by the river mile.
- Tributary monitoring stations are presented as the river mile first, followed by the three letter code for the waterbody on which the station is located. Waterbody codes and associated waterbody names are presented in Table 2-6.

Table 2-5. Fish species abbreviations

Fish abbreviation	Fish name	Fish abbreviation	Fish name
BC	black crappie	RES	redear sunfish
BJS	black jumprock sucker	RHS	redhorse sucker
BLC	blue catfish	RWD	riverweed darter
BGS	bluegill sunfish	RB	roanoke bass
BHC	bluehead chub	RD	roanoke darter
C	carp	RHG	roanoke hogsucker
CC	channel catfish	RB	rock bass
CHB	chub	SRS	shorthead redhorse sucker
FD	fantail darter	SMB	smallmouth bass
FHC	flathead catfish	SPB	spotted bass
GS	gizzard shad	STB	striped bass
GRS	golden redhorse sucker	SF	sunfish
GSF	green sunfish	WE	walleye
LMB	largemouth bass	WB	white bass
MM	margined madtom	WC	white crappie
MS	mixed sunfish species	WP	white perch
NHS	northern hogsucker	WS	white sucker
QCS	quillback carpsucker	YP	yellow perch
RBS	redbreast sunfish		

Table 2-6. Monitoring station waterbody ID codes

Station waterbody code	Waterbody name
BHA	Buffalo Creek
BHE	Beechtree Creek
BOR	Big Otter River
BWC	Black Walnut Creek
CBA	Catawba Creek
CDN	Cedar Run
CRE	Childrey Creek
CUB	Cub Creek
DIF	Difficult Creek
FRV	Falling River
GLA	Glade Creek
GNE	North Fork Goose Creek
GSE	Goose Creek
GSF	South Fork Goose Creek
HIL	Hill Creek
HTA	Hunting Creek
LNA	Long Branch
LOR	Little Otter River
LYH	Lynch Creek
MRC	Mill Creek

Station waterbody code	Stream name
MSN	Mason Creek
PEE	Peters Creek
RAB	Reed Creek
RNF	North Fork
ROA	Roanoke River
ROC	Roanoke Creek
RSF	South Fork Roanoke River
SCE	Sycamore Creek
SEN	Seneca Creek
SSC	Straightstone Creek
SYD	Snyders Branch
TAB	Tanyard Branch
TIP	Turnip Creek
TKR	Tinker Creek
WPP	Whipping Creek
XCN	Unnamed Tributary to Roanoke River
XXX	Unnamed Tributary to Roanoke River
XXZ	Unnamed Tributary to Roanoke River
ZZZ	Unnamed Tributary to Roanoke River

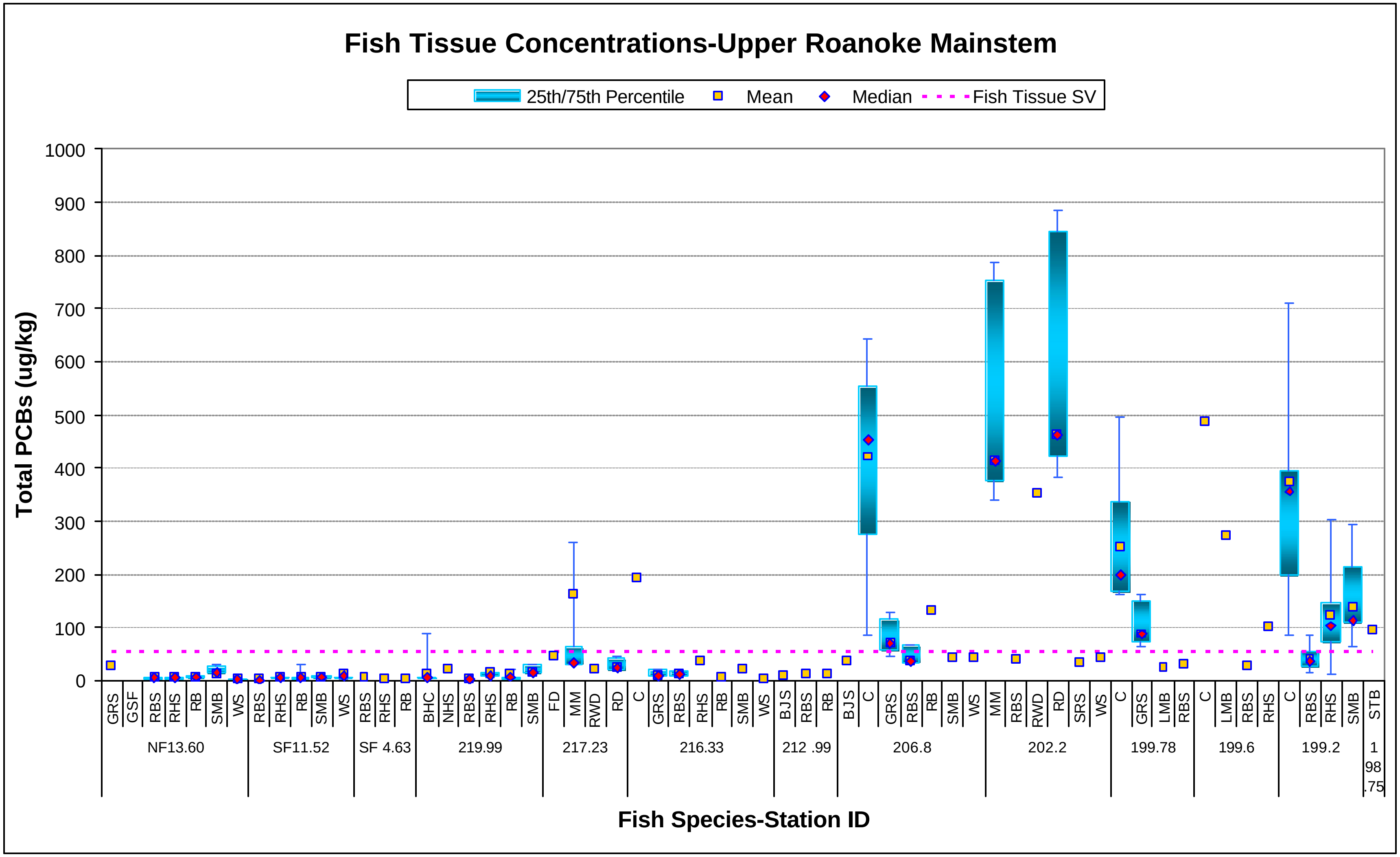

Figure 2-9. Fish tissue monitoring results for upper Roanoke River mainstem.

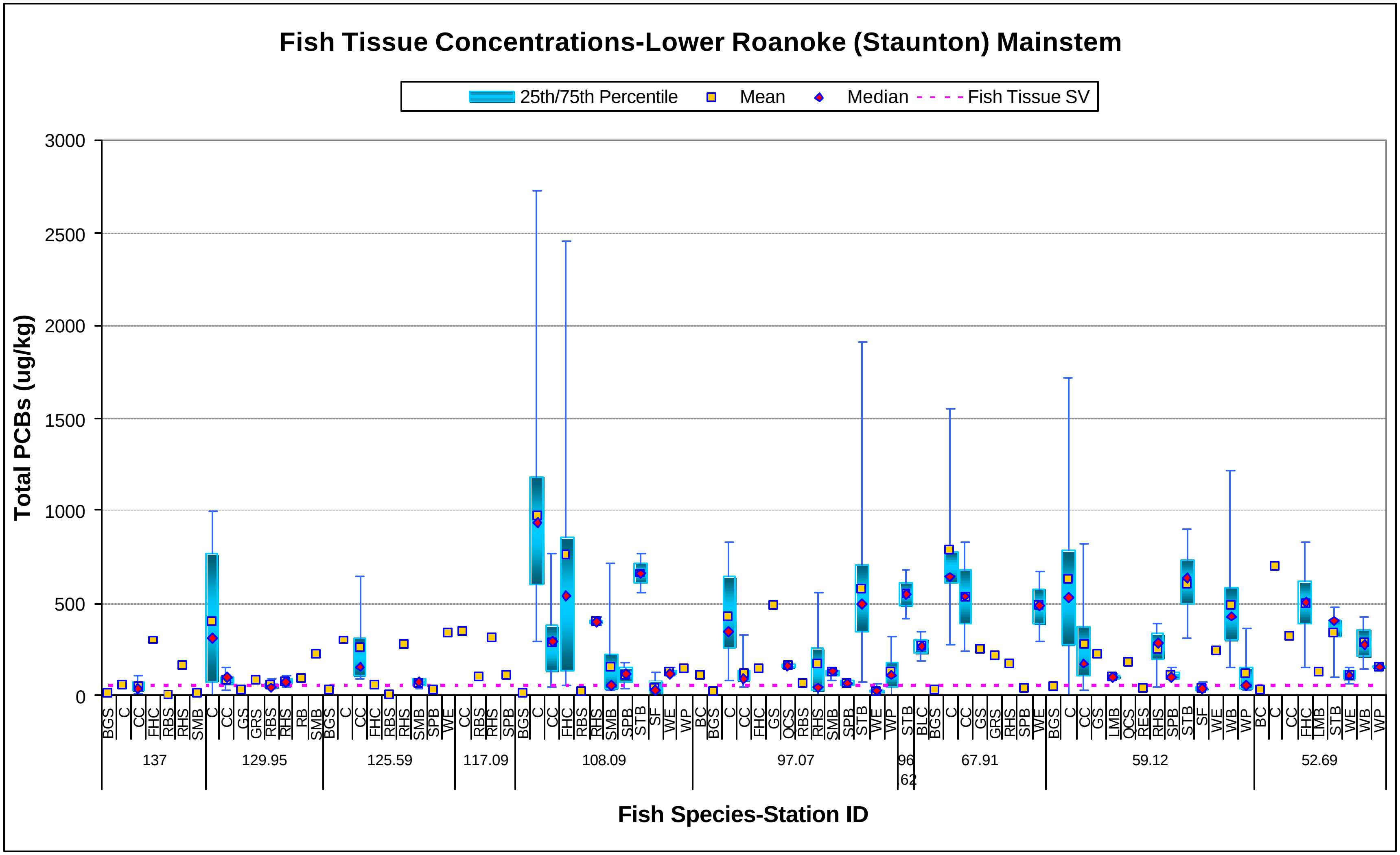

Figure 2-10. Fish tissue monitoring results for lower Roanoke (Staunton) River mainstem.

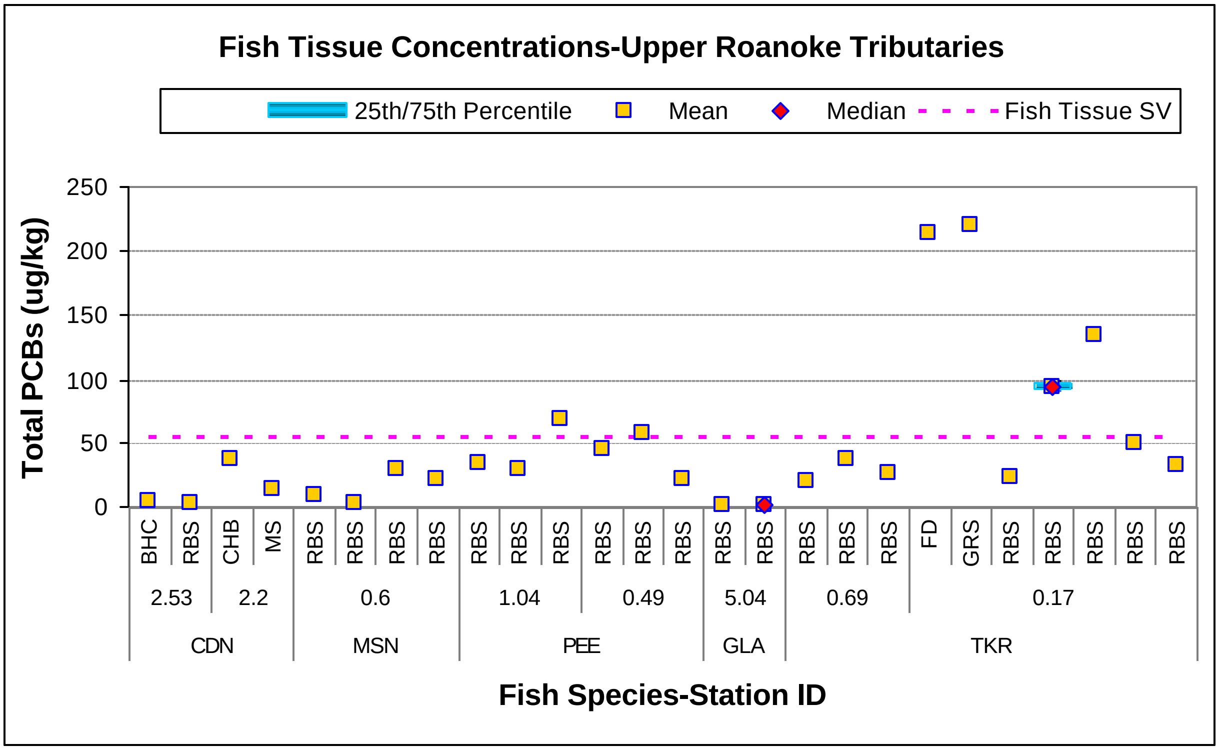

Figure 2-11. Fish tissue monitoring results for upper Roanoke River tributaries.

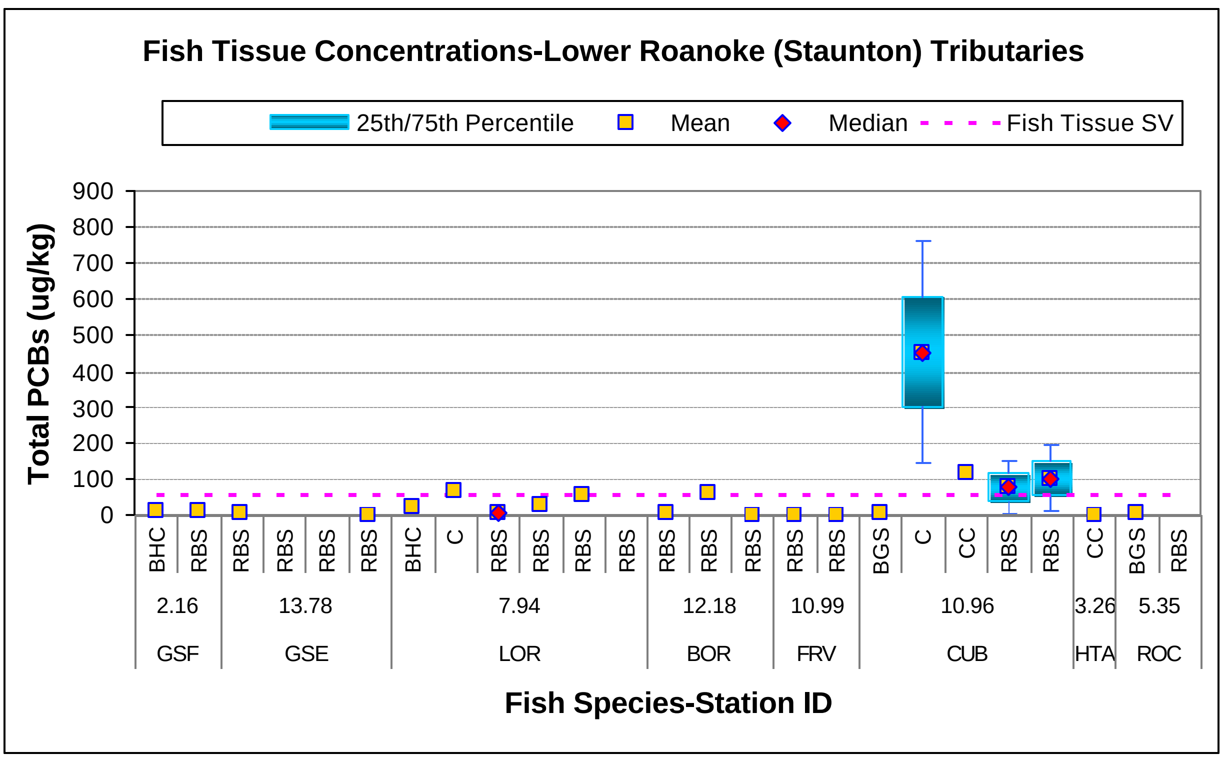

Figure 2-12. Fish tissue monitoring results for lower Roanoke (Staunton) River tributaries.

Sediment PCB Results

Figures 2-13 and 2-14 present the 25th–75th percentile, range, average, and median of tPCBs concentrations recorded at sediment monitoring stations summarized for the entire period of record. To maintain a reasonable scale, outliers in the dataset are represented as text boxes that give the average tPCBs concentration at a monitoring station. Monitoring results are grouped by watershed section and have been broken out into mainstem (Figure 2-13) and tributary stations (Figure 2-14). Stations are presented in an upstream–downstream progression for spatial analysis purposes according to the station river-mile code. Station IDs are given as presented in Figures 2-7a and 2-7b, which show the locations of sediment monitoring stations (see Section 2.2.1). Station ID waterbody codes and associated waterbody names are given in Table 2-6. Data summaries and location descriptions for sediment monitoring stations are presented in Appendix B.

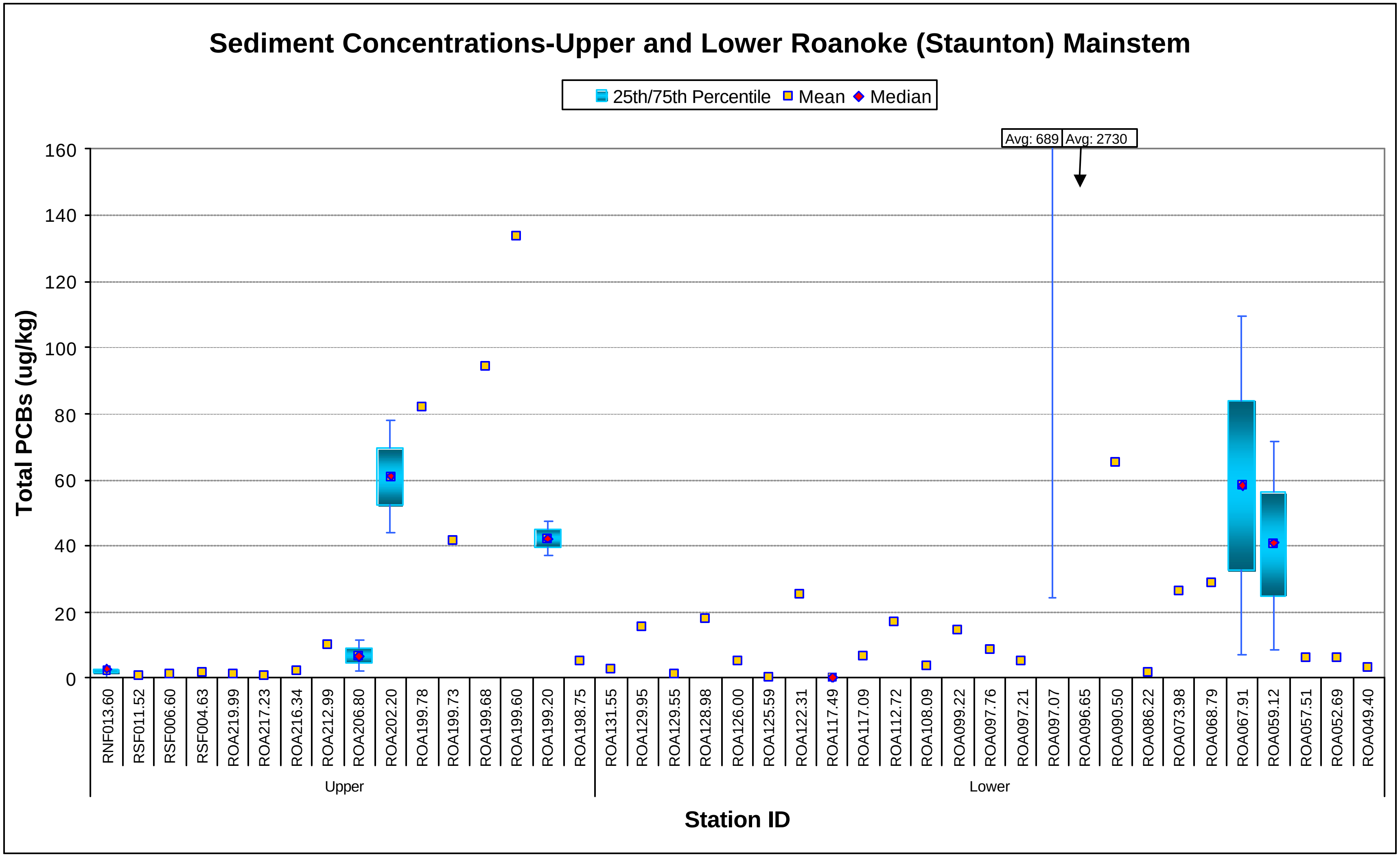

Figure 2-13. Sediment monitoring results for upper and lower Roanoke (Staunton) River mainstem.
Note: To maintain figure scale, text boxes present the average tPCBs concentration at stations with values significantly higher than other stations

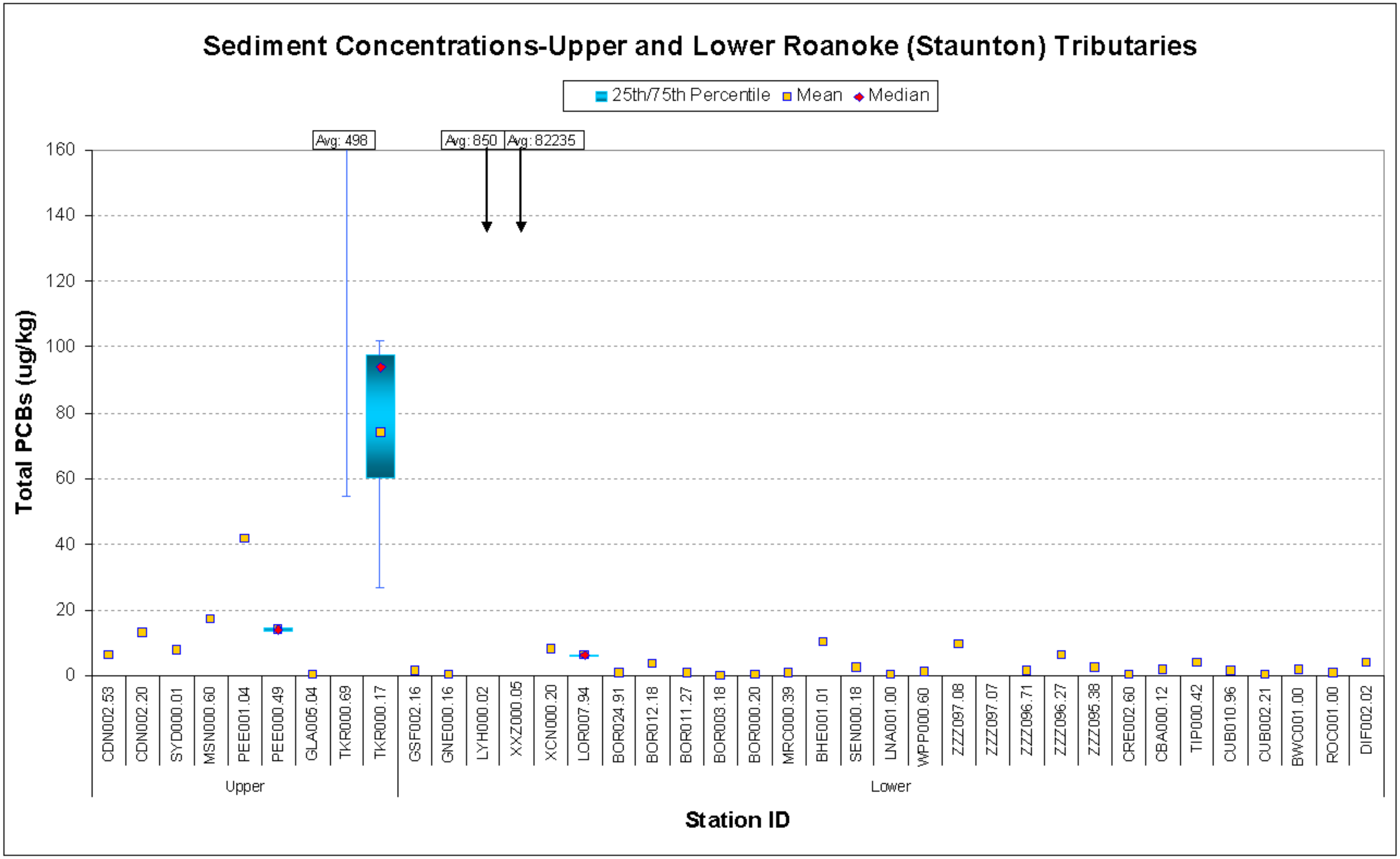

Figure 2-14. Sediment monitoring results for upper and lower Roanoke (Staunton) River tributaries.
Note: To maintain figure scale, text boxes present the average tPCBs concentration at stations with values significantly higher than other stations

2.2.3. Fish Tissue and Sediment Data Analysis Summary

Upper Roanoke Segment (headwaters to Roanoke arm of Smith Mountain Lake):

- Flathead catfish, margined madtom, and carp had the highest average PCB concentrations.
- The highest average fish tissue concentration was observed at station ROA202.20 (Roanoke River near the 13th St. Bridge).
- In general, average fish tissue PCB concentration levels are higher at stations farther downstream. PCB concentrations are observed in fish species collected along the entire VADEQ impaired segment but become > 500 ppb downstream of Peters Creek at station ROA206.80 (Roanoke River near Wasena Park at Route 11 bridge). Peters Creek coincides with the city limits of Roanoke.
- Higher PCB levels were noted downstream of Roanoke River mile 206.80 for all species that were collected both above and below this location.
- Average PCB concentrations exceeded the VADEQ impairment threshold (54 ppb) for at least one species at all stations downstream of Roanoke River mile 206.80.
- Tinker Creek—station TKR000.17 (Tinker Creek near Route 24)—recorded the highest average fish tissue PCB concentrations for a tributary.
- An increasing trend in average sediment PCB concentration is also observed downstream of Peters Creek. Concentrations reach a maximum at station ROA199.60 (Roanoke River above Niagra Dam). The dam is likely an area of suspended solids deposition.
- The only location of high sediment PCB concentrations in a tributary is observed at the mouth of Tinker Creek. High fish tissue and sediment PCB concentrations on and directly downstream of Tinker Creek suggest the possibility of PCB source(s) in this general location.

Lower Roanoke (Staunton) Segment (Leesville Dam downstream to Kerr Reservoir):

- The highest average PCB concentrations in the Roanoke River Basin were noted for lower Roanoke (Staunton) stations.
- The majority of fish species had average concentrations greater than the VADEQ impairment threshold. For fish species with more than 10 samples, sunfish had the lowest concentrations overall.
- Carp, striped bass, and flathead catfish had the highest average PCB concentrations.
- Downstream of Seneca Creek, station ROA108.09 (Roanoke River near Long Island) recorded the highest fish tissue PCB concentrations.
- In general, average fish tissue PCB concentrations are higher downstream of station ROA108.09 between the towns of Altavista and Brookneal.
- Average fish tissue concentrations seem to decrease between mainstem stations ROA108.09 and 97.07, near the town of Brookneal, before increasing again downstream at river mile 67.91, near Route 746, and generally decreasing thereafter.
- Exceedances of the VADEQ fish tissue threshold PCB concentration were observed on three tributaries, Little and Big Otter rivers and Cub Creek. The Little Otter River is a tributary to the Big Otter and flows through the city of Bedford. Sediment data collected at stations on the Big Otter River and its tributaries showed a maximum concentration of 5 ppb.
- Cub Creek recorded the highest average fish tissue PCB concentrations of any tributary stream segment, although the only sediment sample collected in the area was found to have concentration of less than 2 ppb.
- The only sediment monitoring stations on tributaries to record exceedances of the VADEQ SV were on Lynch Creek near Altavista Park (LYH000.02), an unnamed tributary located just west of the

Altavista STP that flows through the known PCB contaminated site BGF Industries (XXZ000.05), and an unnamed tributary near the town of Brookneal at Route 501 (ZZZ097.07).

- Two sediment monitoring stations on the Roanoke River mainstem recorded concentrations exceeding the VADEQ SV (ROA097.07 and 96.65). Both of these are near the town of Brookneal.
- Sediment and fish tissue monitoring data suggest that PCB sources might be in the towns of Altavista and Brookneal.

2.3. Water Column PCB Results

VADEQ conducted a special study in the Roanoke River basin in fall 2005 through spring 2008. The study was designed, in part, to augment the existing water quality record in support of TMDL development. Water quality samples were collected during low-flow and high-flow conditions at 29 monitoring locations throughout the watershed. Because of the hydrophobic properties of PCBs, earlier analytical methods used to process samples collected for prior monitoring studies routinely failed to detect measurable concentrations of PCBs. The special study results were processed using a high-resolution, low-detection level analysis method (1668A) specifically to account for PCBs' hydrophobic properties.

Figures 2-15 and 2-16 present the 25th–75th percentile, range, average, and median of tPCBs concentrations recorded during high- and low-flow conditions at the special study water quality monitoring stations for the upper and lower Roanoke (Staunton). Where measured PCB concentrations at a station were significantly higher than at other stations located in the same section, the average concentration is given in a text box to maintain the scale of the figure. The TMDL water quality targets for the upper and lower sections are also included for points of reference. Stations are presented in an upstream–downstream progression for spatial analysis purposes according to the station river mile code and tributary point of confluence with the Roanoke River mainstem. Note that data collected in fall 2005 have been excluded from the analysis because of concerns of sample contamination. Data summaries for the special study water quality monitoring stations are presented in Appendix B.

Station IDs have been condensed for Figures 2-15 and 2-16 for the purpose of presentation where monitoring was done for only high- or low-flow conditions. Station IDs differ from those presented in the map of water column monitoring station locations (Figure 2-8) in that river miles are expressed as the highest significant digit, not as a standard five digits (eg. 56.1 vs. 056.10). Station ID waterbody codes and associated waterbody names are given in Table 2-6.

Trends in the water quality monitoring data are very similar to those observed in the fish tissue and sediment monitoring record. In the upper section of the Roanoke, a significant increase in tPCBs concentrations occurs between river mile 207.08 and 204.76. Along this length of the mainstem, the surrounding urban land use becomes progressively denser as one moves toward the city center of Roanoke. Many of the suspected contaminated sites in the upper section are also in this area, as discussed in Section 3.1. Upstream of river mile 207.08, all monitoring data is below the water quality target. High- and low-flow PCB concentrations peak at river mile 202.20 just upstream of the Tinker Creek confluence. High-flow concentrations decrease at river mile 199.20 at Niagra Dam, which could be due to the backwater effect of the dam and the reduction of flow turbulence and the resuspension of contaminated sediments. In addition, at all monitoring locations, low-flow tPCBs concentrations are lower than high-flow concentrations. This gives strong evidence of increased loading during storm events, which cause stormwater runoff and streambed sediment resuspension.

In the lower section of the Roanoke (Staunton), increases in water column tPCBs concentrations also correspond to the locations of suspected contaminated sites. At river mile 129.55, along the town of Altavista, a noticeable increase in tPCBs concentrations is seen. This increase becomes significant as one moves downstream to river mile 124.59 where high-flow concentrations exceeded 4,000 picograms per liter (pg/L). Very high water concentrations were recorded on two tributaries to the mainstem above this point at the mouth of Lynch Creek (LYH000.17) and an unnamed tributary (XLN000.00) that drains industrial sites in Altavista.

Water column concentrations remain elevated moving downstream to river mile 97.76, adjacent to the town of Brookneal, where the measured high-flow concentration also exceeded 4,000 pg/L. Downstream of Brookneal high-flow concentrations monitored on the Roanoke mainstem decrease, but remain well above the water quality target. Interestingly, below river mile ROA90.50 as the river approaches the Kerr Reservoir and the water starts to slacken, low-flow PCB concentrations begin to exceed high-flow concentrations. This could be because the reservoir is causing contaminated sediment to settle out and accumulate in these areas, which then contributes PCBs to the water column at a steady rate that is more apparent during low-flow conditions. Sediment monitoring data seem to generally support this conclusion, with an increase in PCB concentration noticeable downstream of river mile 97.07 (see Figure 2-13). Monitoring results for tributaries in the lower section are generally below the water quality target, with the exception of the two that run through the town of Altavista and the Big Otter River (BOR000.62), which exceeded criteria during high-flow conditions.

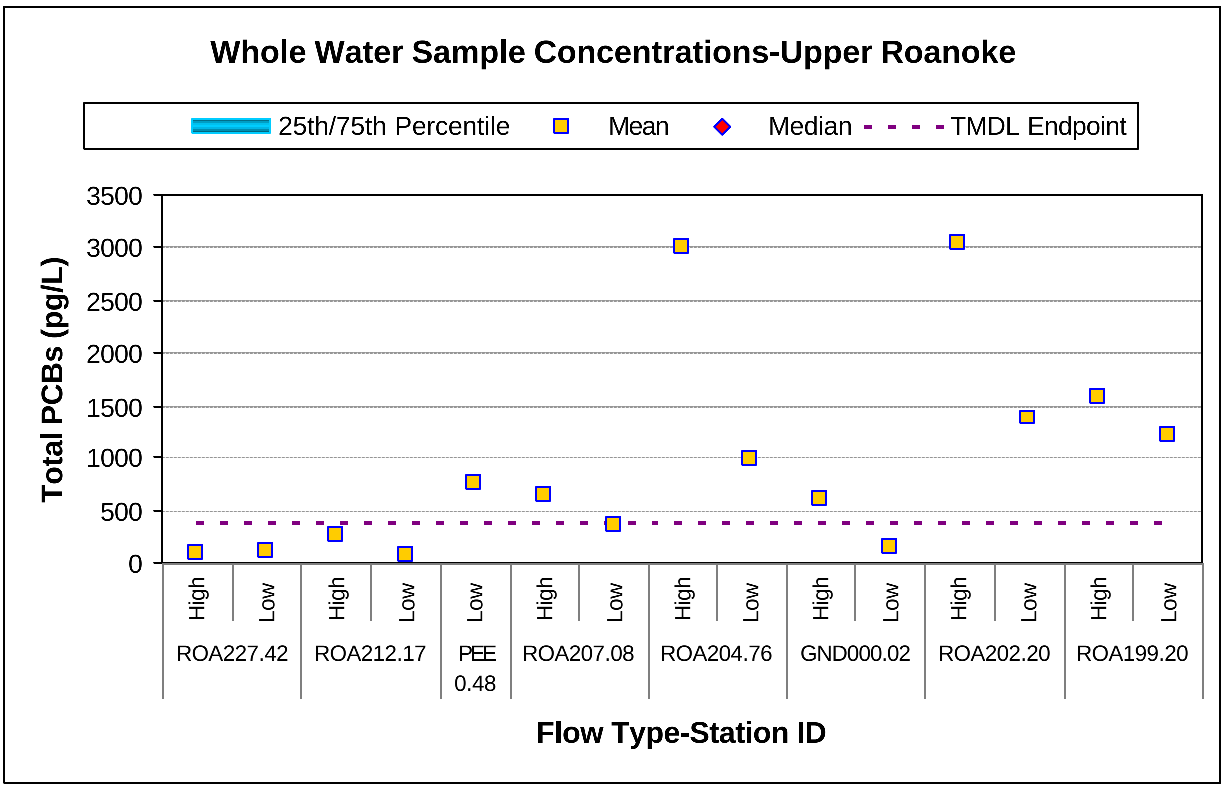

Figure 2-15. Special study water column monitoring results for the upper Roanoke River.

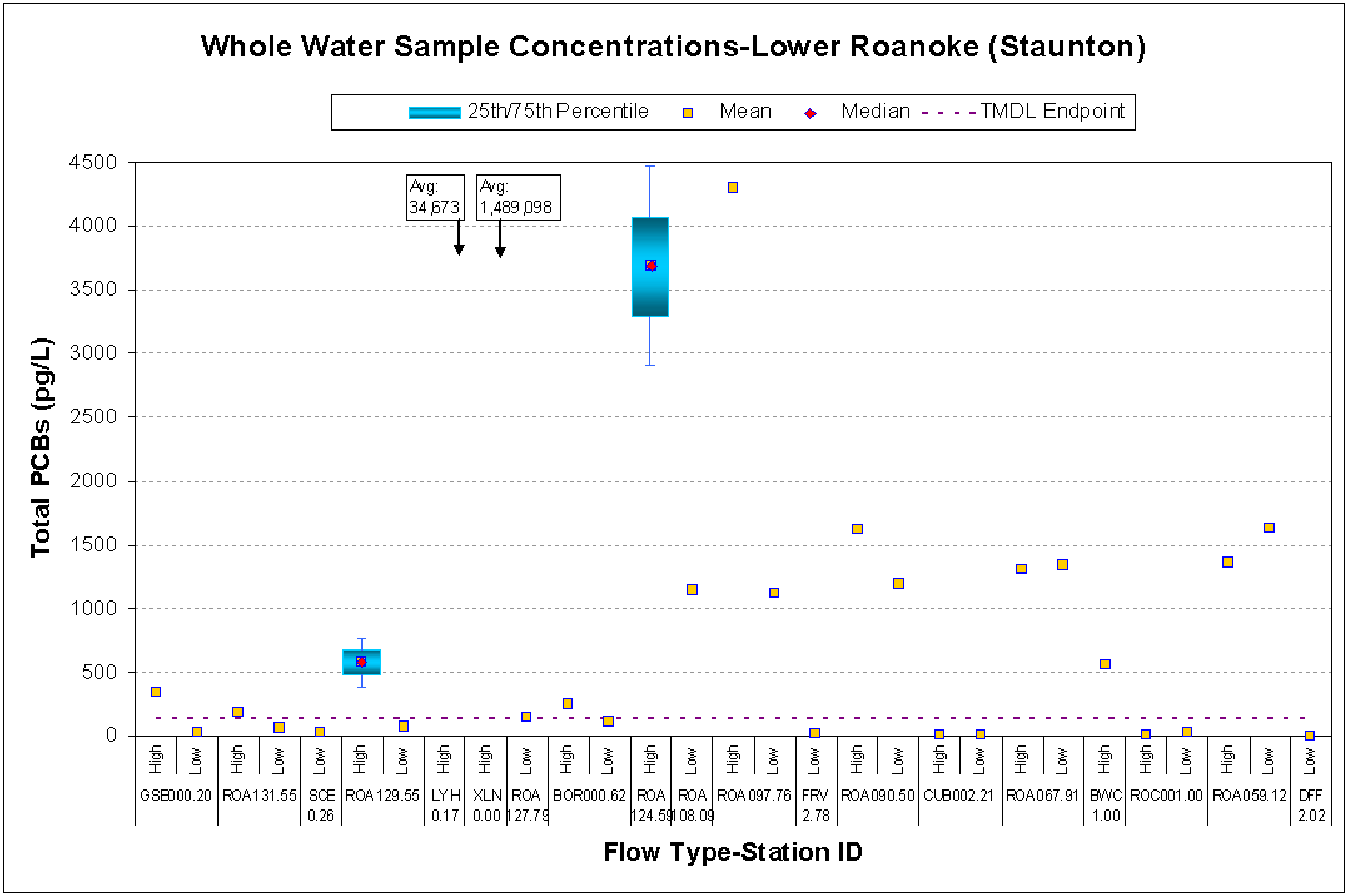

Figure 2-16. Special study water column monitoring results for the lower Roanoke (Staunton) River.
Note: To maintain figure scale, text boxes present the average tPCBs concentration at stations with values significantly higher than other stations

3. SOURCE ASSESSMENT

This section presents the information collected to date on point and nonpoint sources of PCBs in the Roanoke River basin. The development of PCB TMDLs in the Roanoke River watershed is subject to adaptive implementation and on-going source investigation whereby sources of PCB contamination are continuously being reviewed and updated based on the best available information. The following discussion of PCB sources, therefore, should be considered the most up-to-date information at the time of the development of these TMDLs, rather than a complete and final characterization. The discussion that follows is limited to identifying the sources represented in the TMDL. Discussion of the representation of sources within the TMDL model framework is presented in Section 5.0 and Appendix G.

For the purposes of this TMDL, sources of PCB loadings to a waterbody are defined as either current or legacy. Current sources generate PCB loads that have a defined, disruptable pathway to a waterbody. Such sources, in theory, can be controlled without eliminating the source of PCBs by blocking the pathway. Examples of current sources include PCB-contaminated soils that wash off from upland areas, leachate from landfills and industrial disposal areas, leaking transformers and storage containers, discharges of PCB-contaminated effluent, local deposition of atmospheric PCBs accumulated from off-gassing contaminated sites, and a variety of other sources.

Legacy sources generate PCB loads to a waterbody that cannot be easily controlled because there is no disruptable pathway from the source to the affected waterbody. Control of the source requires its direct removal. In all cases, the source exists at an interface with the waterbody where there is continuous exchange of material. Examples of legacy sources include in-stream contaminated sediments, stream bank soils that are not part of a contaminated site, biota, and background atmospheric deposition to surface waters.

Both current and legacy sources are represented in the TMDL model framework. For discussion of the methodology used to define source loads, see Section 5.0 and Appendix G.

3.1. Source Inventory/Current Sources

VADEQ has conducted several site investigations and special studies in recent years to assess the spatial extent of PCB contamination in the Roanoke basin and to identify current sources generating PCB loads in the watershed. An inventory was created to organize all existing data related to efforts to identify and characterize facilities/sites where PCBs may have been used, stored, or disposed of.

The information compiled includes various memos and other correspondence, public meeting records, site investigations, VADEQ monitoring data and special studies, pollution complaint records, solid waste facility information, VPDES facility information, Toxic Substance Control Act (TSCA) data, Comprehensive Environmental Response Compensation and Liability Act (CERCLA) records, Resource Conservation and Recovery Act (RCRA) database records, and other available information. Such records were examined in conjunction with the available PCB fish tissue and sediment monitoring data to identify possible sources of PCBs in the Roanoke River watershed. In the early stages of the TMDL study, a PCB source database was created to inventory historical PCB monitoring data at facilities in the upper Roanoke watershed.

After a review of the collected records and monitoring data, the conclusions that were drawn were used to design a 2005 special study that included monitoring effluent at selected facilities, collecting water column samples, and deploying SPMDs at various locations throughout the watershed. This special study was ultimately expanded into the fall 2005 through spring 2008 special study, which included three rounds of sampling conducted October 13, 2005–January 31, 2006, August 7, 2007–September 10, 2007, and July 1, 2007–May 9, 2008. Monitoring for the expanded study included the media originally planned to be sampled in 2005, as well as sediment and facility sludge monitoring.

3.1.1. Point Sources

Twelve point sources are represented as current PCB sources in the TMDL. Three sites (Dan River, Inc.; Burlington Industries; and the town of Altavista Sewage Treatment Plant) are also represented as nonpoint sources (see Section 3.1.2). Table 3-1 lists the sites represented as point sources and Figure 3-1 shows their locations.

Facility outfalls were represented as PCB point sources if results from the 2005–2008 VADEQ special study found the facility has contributed a PCB load. VADEQ also requested that applicable facilities be included as determined using their PCB point source monitoring guidance (VADEQ, 2009).

Table 3-1. Model PCB point source dischargers

NPDES facility name	Facility type	NPDES ID	Outfall	Design flow (MGD)	Receiving stream
Dan River, Inc - Brookneal	Fabrics finishing	VA0001538	001	1.326	Roanoke (Staunton) River
Steel Dynamics	Steel works	VA0001589	005	0.067	Peters Creek
Norfolk Southern Railway Co – Shaffers Crossing	Railroads, line-haul operating	VA0001597	002	0.07	Peters Creek
ITG Burlington Industries LLC Hurt Plant	Fabrics finishing	VA0001678	001	3.42	Roanoke River
Altavista - Wastewater Treatment Plant	Sewerage systems	VA0020451	001	3.6	Roanoke River
Brookneal - Staunton River Lagoon	Sewerage systems	VA0022241	001	0.078	Roanoke (Staunton) River
Montgomery County PSA - Shawsville STP	Sewerage systems	VA0024031	001	0.2	SF Roanoke River
Roanoke City Regional Water Pollution Control	Sewerage systems	VA0025020	001	55	Roanoke River
Blacksburg Country Club	Sewerage systems	VA0027481	001	0.035	NF Roanoke River
Montgomery County PSA - Elliston Lafayette WWTP	Sewerage systems	VA0062219	001	0.25	SF Roanoke River
Old Dominion Electric Cooperative - Clover	Electric services	VA0083097	001	1.735	Roanoke River
Old Dominion Pittsylvania Power Station	Electric services	VA0083399	001	0.192	Roanoke (Staunton) River

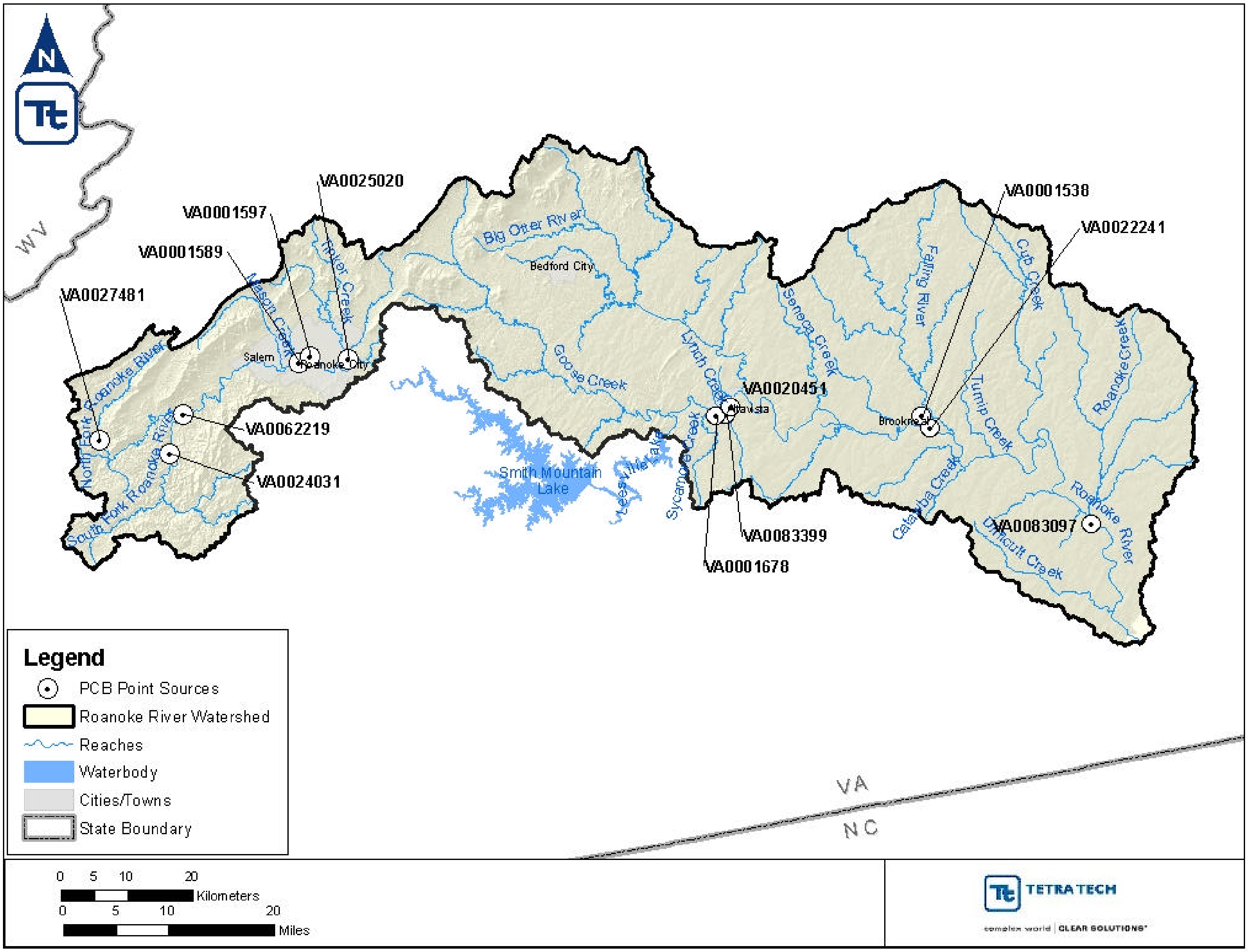

Figure 3-1. Model PCB point sources.

3.1.2. Nonpoint Sources

Twenty-one nonpoint sources are represented as current PCB sources in the TMDL. Three sites (Dan River, Inc.; Burlington Industries; and the town of Altavista Sewage Treatment Plant) are both point and nonpoint sources (see Section 3.1.1). Table 3-2 lists the sites represented as nonpoint sources and Figures 3-2 through 3-4 present their locations.

Areas represented as nonpoint sources include sites where analysis of on-site soil samples found measurable concentrations of PCBs. Available results for on-site soil sampling were obtained from four sources: *PCB Source Investigation: Altavista and Hurt* (VADEQ 1999), *Analysis of Brownfield Cleanup Alternatives Former Virginia Scrap Iron & Metal Company, Inc. Property* (City of Roanoke 2008), a *Site File Review for PCBs in the Roanoke River Watershed* that was completed as part of a CERCLA preliminary assessment (USEPA 1999a), and the VADEQ PCB source survey database.

Not all TMDL-represented nonpoint sources have available soil sampling results confirming PCB contamination. The Altavista east- and west-town dumps and Dan River, Inc., are characterized as contaminated sites because of the following considerations:

- The Altavista east- and west-town dumps were included as sampling sites in the *Altavista/Hurt PCB Source Investigation* (VADEQ 1999) but were ultimately not sampled because of concerns of safety risks. Numerous facilities adjacent to the dumps are known contaminated sites, however, and the dumps are known to be historical disposal areas for local industry.
- Dan River, Inc., is a fabrics finishing plant similar to the known contaminated site BGF industries. Effluent monitoring results also show that the facility has contributed a PCB load.

Research has also shown that off-gassing from PCB-contaminated sites can cause local deposition of atmospheric PCBs and contribute loads to a waterbody (Totten et al. 2004). Although no data exists to represent this process for the Roanoke River watershed, it could be considered in future TMDL studies if data become available. Background atmospheric deposition of PCBs represented as a legacy source is represented in the TMDL. For further information, see the discussion of legacy sources.

Table 3-2. Model PCB contaminated sites

Site name	NPDES ID	Site/facility description	County/city	Receiving stream
A. O. Smith		Electric motor manufacturing	Campbell	Roanoke (Staunton) River, UT
Altavista STP	VA0020451	Sewerage system	Campbell	Roanoke (Staunton) River
American Viscose Co.		Fabrics finishing plant	Roanoke City	Roanoke River
Appalachian Power Co. (APCO) Yard		Electric Services	Roanoke City	Roanoke River
BGF Industries[a]		Fabrics finishing plant	Campbell	Roanoke (Staunton) River, UT
Burlington Industries-Altavista Hurt[a]	VA0001678	Fabrics finishing plant	Pittsylvania	Sycamore Creek
Dan River, Inc.	VA0001538	Fabrics finishing plant	Campbell	Roanoke (Staunton) River
Dixie Caverns Landfill	VAD980552095[b]	Landfill	Roanoke	Roanoke River
East town Dump-Altavista		Landfill	Campbell	Roanoke (Staunton) River
English Construction		Landfill	Pittsylvania	Roanoke (Staunton) River
Evans Paint	VASFN0305570[b]	Former chemical manufacturing plant (Evans Chemical)	Roanoke City	Roanoke River
Jacob Webb			Roanoke City	Roanoke River
Lane Furniture Co.		Site of old furniture manufacturing plant	Campbell	Roanoke (Staunton) River
Norfolk Southern 1		Railroads, line-haul operating	Roanoke City	Roanoke River
Norfolk Southern 2		Railroads, line-haul operating	Roanoke City	Roanoke River
Oil distributors-Altavista		Current location of three adjacent oil distributors and common *wet* area	Campbell	Lynch Creek
Roanoke River Floodway Bench Cuts		Areas along the Roanoke River mainstem where the floodplain has been expanded	Roanoke	Roanoke River
Schrader Bridgeport[a]		Metal plating and rubber valve manufacturing	Campbell	Roanoke (Staunton) River, UT
Tinker-American Electric Power (AEP) property		Electric Services	Roanoke City	Roanoke River
Virginia Scrap Iron Co.	VRP408[c]	Site of an old metal scrap yard	Roanoke City	Roanoke River
West town dump-Altavista		Landfill	Campbell	Lynch Creek

a. Where a contaminated site is covered by a stormwater permit, the source is considered a stormwater site for TMDL purposes (See Section 3.1.3)
b. EPA Superfund ID#

c. Virginia Voluntary Remediation Program (VRP) site#

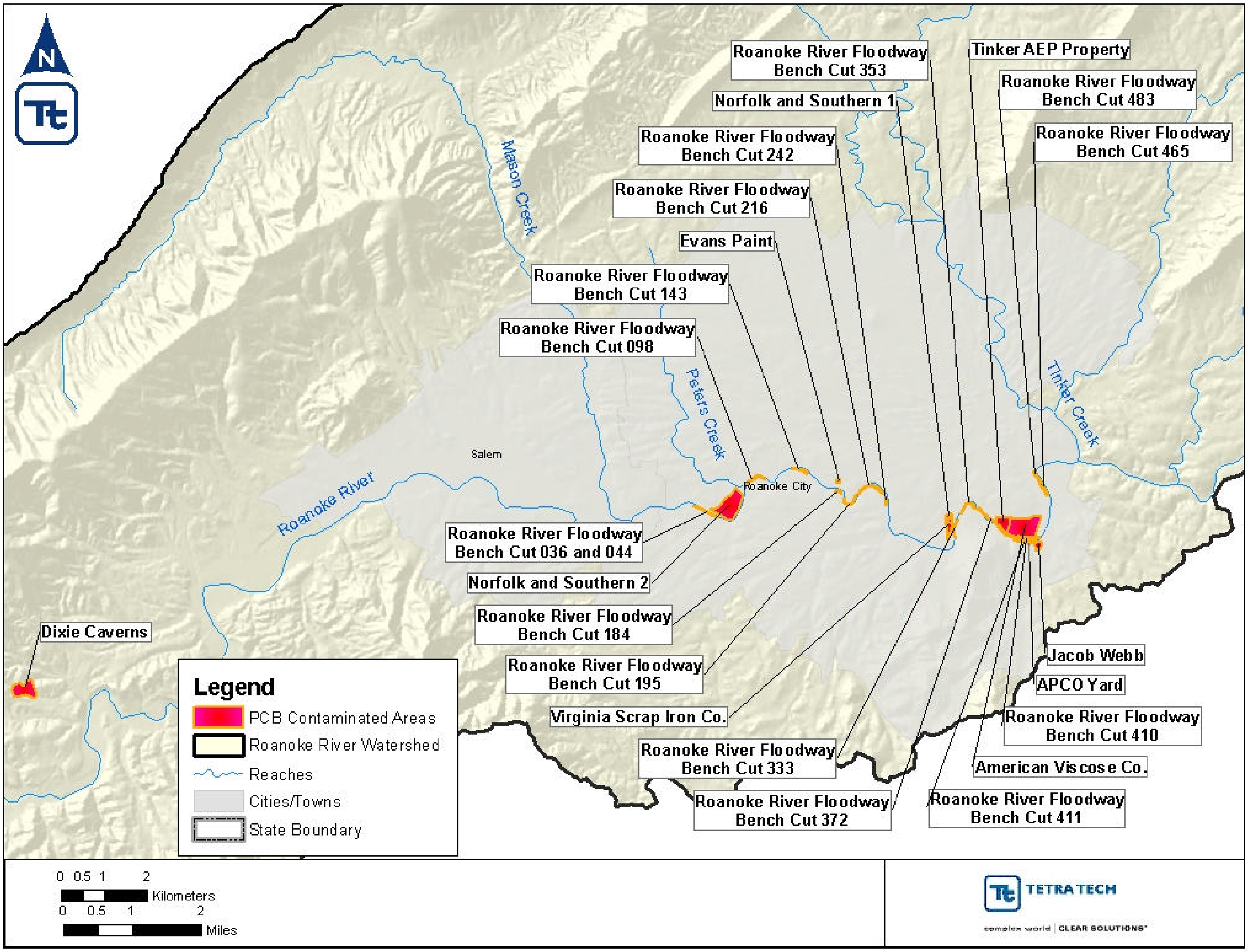

Figure 3-2. Model nonpoint source areas—Roanoke.

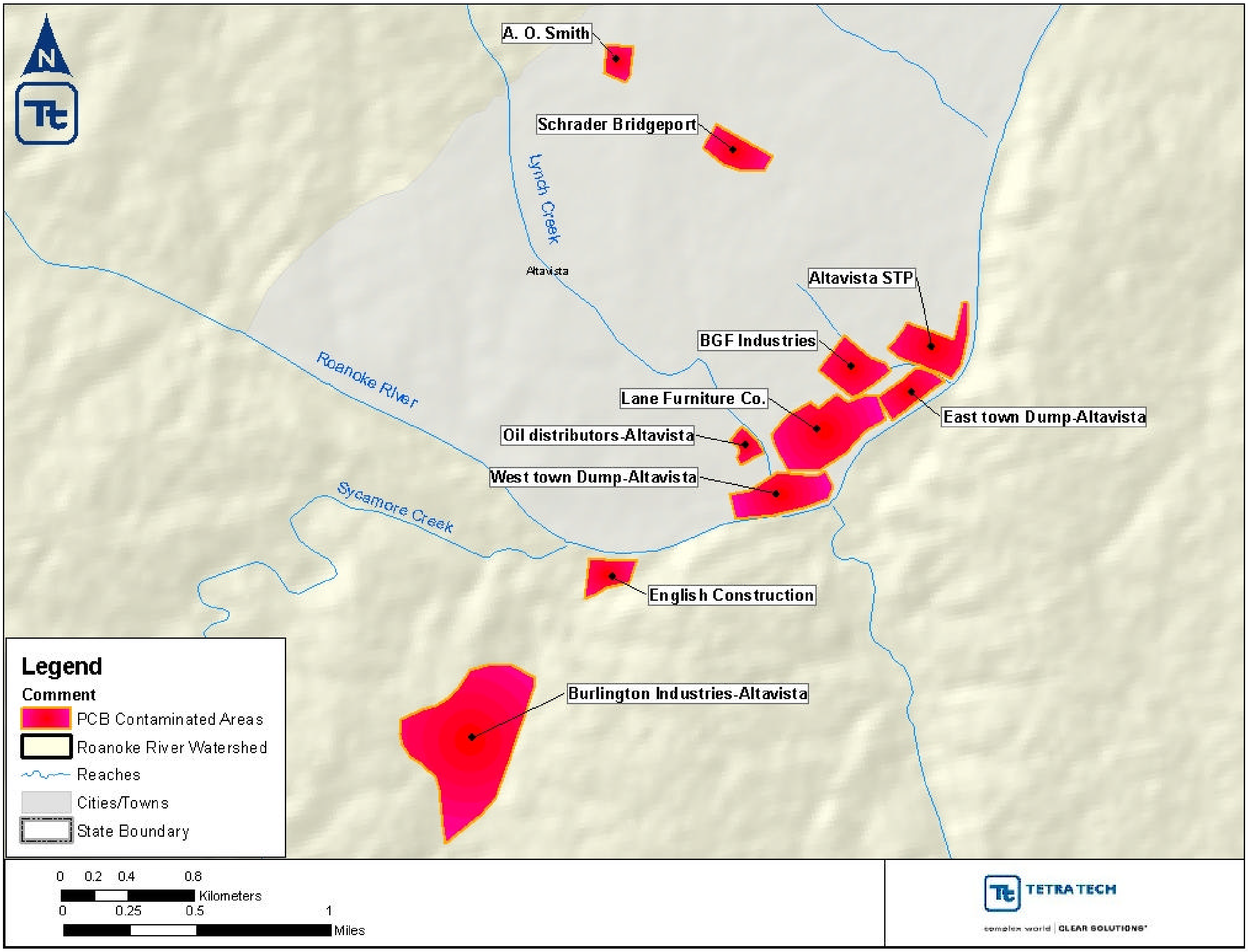

Figure 3-3. Model nonpoint source areas—Altavista.

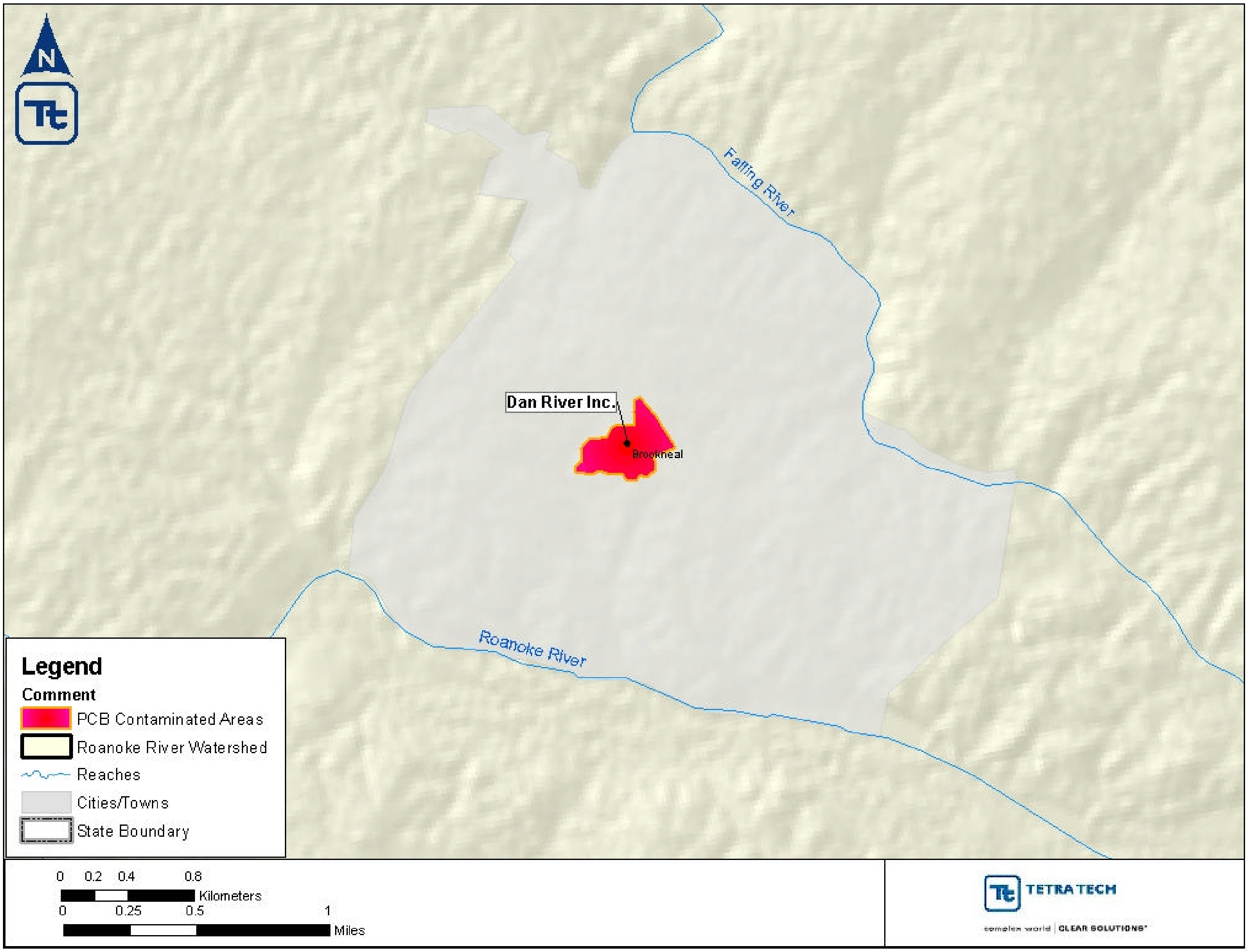

Figure 3-4. Model nonpoint source areas—Brookneal.

3.1.3. MS4s/Stormwater Permits

On November 22, 2002, EPA's Office of Wetlands, Oceans and Watersheds and Office of Wastewater Management issued a memorandum, *Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs* (USEPA 2002), that updated previous regulation and finalized requirements under which municipal separate storm sewer systems (MS4s) are treated as point sources when calculating TMDLs. As a result, pollutant loadings from MS4s and facilities and sites issued general stormwater permits must be explicitly accounted for when calculating TMDLs.

MS4s in the Roanoke River basin are listed in Table 3-3 and presented in Figure 3-5. A list of active stormwater permits issued to facilities and sites in the basin is provided in Appendix C. Loads from contaminated sites within the spatial extent of an MS4 or site permitted for stormwater are considered a component of the associated MS4 or general stormwater permit. Where a stormwater permit is located within an MS4, the load is assigned to the stormwater permit. Section 5.0 and Appendix G discuss the representation of loads generated by nonpoint source contaminated sites.

Table 3-3. MS4s in the Roanoke River watershed

MS4 permit holder	Permit number	Area (acres)
Roanoke County	VAR040022	28,907
City of Roanoke	VAR040004	23,577
Botetourt County	VAR040023	5,180
City of Salem	VAR040010	9,332
Town of Blacksburg	VAR040019	1,613
Town of Christiansburg	VAR040025	1,193

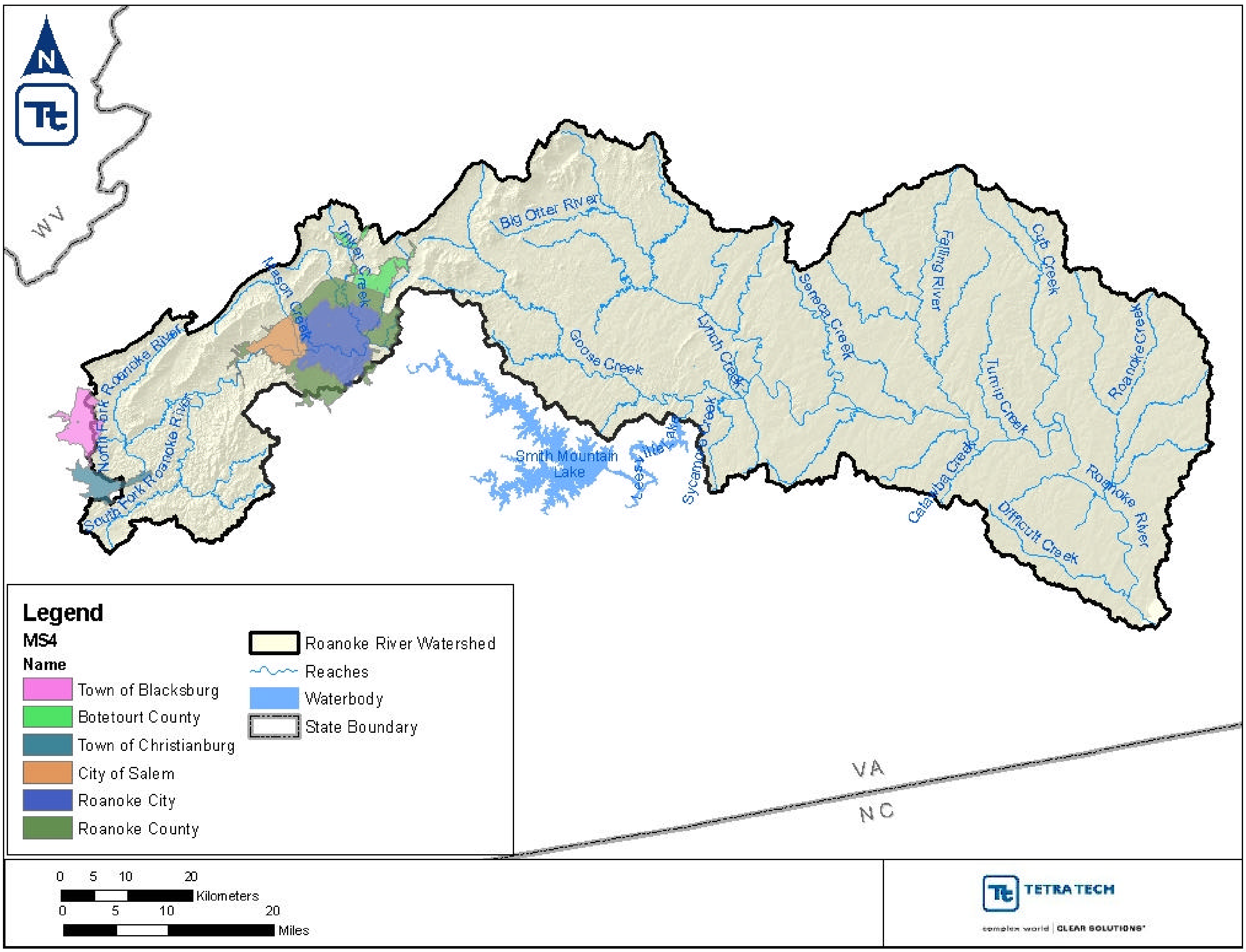

Figure 3-5. Model MS4 areas.

3.2. Legacy Sources

Legacy sources represented in the TMDL include loadings of PCBs from contaminated streambed and background atmospheric deposition of PCBs to surface waters. These sources exist at an interface with the affected waterbody and do not have a loading pathway that can be easily controlled.

3.2.1. Atmospheric Deposition

The wide-spread use of PCBs before their ban in the 1970s coupled with their stable molecular structure has caused a generalized distribution of the pollutant in air, soil, and water at background concentrations. The net flux of gaseous PCBs between the atmosphere and the surface of a waterbody is a function of the dynamic concentration gradient between the two. Atmospheric deposition has been shown to be a significant pathway of PCB cycling in freshwater systems (PADEP 2001).

3.2.2. Streambed Sediments

Streambed sediments can contain significant concentrations of PCBs from historical or current loadings or both. These PCBs can be released to the water column by resuspension of streambed sediments and desorption of PCBs, desorption of PCBs at the streambed-water column interface, and the direct diffusion of PCBs from lower contaminated sediment layers.

The movement and accumulation of streambed sediments are governed by in-stream processes. Contaminated streambed sediments are available for consumption by aquatic biota, are transported downstream, and can be buried under additional sediments. Downstream transport can result in sediments being flushed out of the system or being trapped behind downstream dams. Existing PCB projects, such as the Hudson River project in New York and the Housatonic River project in Massachusetts, have found that historical discharges have resulted in contaminated sediments, which tend to collect in slow river stretches or reservoirs. The contaminated sediments tend to remain in such depositional areas until they are dredged or dislodged by storms.

4. TMDL TECHNICAL APPROACH

Establishing the relationship between the in-stream water quality targets and source loadings is a critical component of TMDL development. It allows for evaluation of management options that will achieve the desired source load reductions necessary to meet water quality standards. The link can be established through a range of techniques, from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. Ideally, the linkage will be supported by monitoring data that allow the TMDL developer to associate certain waterbody responses with flow and loading conditions.

The objective of the Roanoke PCB TMDL study is to identify the sources of PCB contamination and to determine the reductions required to achieve water quality criteria for PCB impaired segments. This section presents an overview of the modeling approach for developing PCB TMDLs for the Roanoke River basin. For a more detailed discussion of the TMDL technical approach see Appendix G.

4.1. Critical Considerations

The pollutant of concern for the current modeling application is tPCBs. PCBs are a hydrophobic nonpolar organic chemical species that tend to associate with fine sediments. PCBs associate with sediments by the process of adsorption. Adsorption describes the tendency of PCBs to accumulate on the surface of sediments in an aqueous environment as a function of energetic favorability, where the strength of the PCB-sediment association is proportional to the availability of adsorption surfaces (TSS concentration), sediment organic content, and the PCB species degree of chlorination.

Land use in the Roanoke River basin includes extensive areas of largely undeveloped forest and pastoral lands and relatively small areas of concentrated development. Each land use affects the hydrology and sediment loads of the basin in a different way. Available monitoring data, as described in Section 2.2, suggests that potential sources of PCBs are often associated with developed land uses.

4.2. Modeling Framework

A watershed modeling framework, consisting of the Loading Simulation Program C++ (LSPC) with sediment PCB modeling enhancements, was used to develop PCB TMDLs for the Roanoke River basin. A watershed model is a series of algorithms that integrate meteorological forcing data and watershed characteristics to simulate upland and tributary routing processes, including hydrology and pollutant transport. Once a model has been adequately set up and calibrated and the dominant unit processes are deemed representative on the basis of comparison with available monitored conditions, it becomes a useful tool to quantify existing flows and loads from tributaries without gages and from diffuse overland flow sources.

4.2.1. Loading Simulation Program C++ (LSPC)

EPA-approved LSPC (http://www.epa.gov/athens/wwqtsc/html/lspc.html) was selected for Roanoke River watershed modeling. LSPC is a watershed modeling system that includes Hydrologic Simulation Program–FORTRAN (HSPF) algorithms for simulating watershed hydrology, erosion, and water quality processes, as well as in-stream transport processes. During the past several years it has been used to develop hundreds of EPA-approved TMDLs, and it is generally considered the most advanced hydrologic and watershed loading model available.

HSPF is a comprehensive watershed and receiving water quality modeling framework that was originally developed in the mid-1970s. The hydrologic portion of HSPF/LSPC is based on the Stanford Watershed Model (Crawford and Linsley 1966), which was one of the pioneering watershed models. The HSPF framework is composed of modules with components that can be assembled in different ways, depending on the objectives of the project. The model includes three major modules:

- PERLND for simulating watershed processes on pervious land areas
- IMPLND for simulating processes on impervious land areas
- RCHRES for simulating processes in streams and vertically mixed lakes

All three modules include many submodules that calculate the various hydrologic, sediment, and water quality processes in the watershed. Table 4-1 lists the modules from HSPF that are used in LSPC.

Table 4-1. HSPF modules included in LSPC

Receiving water modules (RCHRES)	HYDR	Simulates in-stream hydraulic behavior
	ADCALC	Simulates in-stream advection of dissolved or entrained constituents
	CONS	Simulates in-stream conservative constituents
	HTRCH	Simulates in-stream heat exchange
	SEDTRN	Simulates in-stream behavior of inorganic sediment
	GQUAL	Simulates in-stream behavior of a generalized quality constituent
Watershed modules PERLND/IMPLND	SNOW	Simulates snow fall, accumulation, and melting
	PWATER/IWATER	Simulates water budget for a pervious/impervious land segment
	SEDMNT/SOLIDS	Simulates production and removal of sediment for a pervious/impervious land segment
	PSTEMP	Simulates soil layer temperatures
	PWTGAS/IWTGAS	Estimates water temperature and dissolved gas concentrations in the outflows from pervious/impervious land segments
	PQUAL/IQUAL	Simulates water quality in the outflows from pervious/impervious land segments

Source: (Bicknell et al. 1997)

Spatially, the watershed is divided into a series of subbasins or subwatersheds representing the drainage areas that contribute to each of the stream reaches. These subwatersheds are then further subdivided into segments representing different land uses. For the developed areas, the land use segments are further divided into pervious (PERLND) and impervious (IMPLND) fractions. The stream network (RCHRES) links the surface runoff and subsurface flow contributions from each of the land segments and subwatersheds and routes them through the waterbodies using storage-routing techniques. The stream network is constructed to represent all the major tributary streams, as well as different portions of stream reaches where significant changes in water quality occur.

Important routines for water quality simulation include the QUAL and SED modules, both of which have PERLND/IMPLND and RCHRES components that define the upland and in-stream characteristics of each. Together, these routines provide the basic framework for simulating pollutant loading and transport in a watershed.

5. MODEL SETUP

An LSPC model was configured for the areas contributing to TMDL impaired streams (see Section 1.2) in the Roanoke River basin as a series of hydrologically connected subwatersheds. Configuration of the model involved subdividing the watersheds into modeling units, followed by continuous simulation of flow and water quality for the units using meteorological, land use, soils, stream, and water quality data. Developing and applying the watershed model to address the project objectives involved the following major steps:

1. Watershed Segmentation
2. Configuration of Key Model Components
3. Representation of Watershed Sources
4. Model Calibration and Validation

The model configuration steps are presented briefly in the discussion that follows. For a more detailed explanation of each, see Appendix G.

5.1. Watershed Segmentation

Watershed segmentation refers to subdividing the entire watershed into small, discrete subwatersheds for modeling and analysis. Subwatersheds represent hydrologically connected modeling units and capture the drainage areas of their associated stream segments. The delineated subbasins represent the scale at which model simulations take place.

The Roanoke River watershed was divided into two separate segments for modeling purposes—the upper Roanoke, which extends from its headwaters downstream to Niagra Dam, and the lower Roanoke (Staunton), which includes the length of the River from Leesville Dam downstream to its confluence with the Dan River. These large segments were further subdivided into subbasins primarily using the watershed stream network, locations of PCB sources, and topographic variability, and secondarily using the locations of available water quality, fish tissue, and sediment PCB monitoring stations; the locations of USGS continuous stream flow gages; and existing watershed boundaries [Virginia subwatersheds (VAWATBOD) developed by VADEQ]. Delineating the Roanoke River watershed resulted in 45 and 107 model subwatersheds for the upper and lower Roanoke (Staunton) segments, respectively (Figures 5-1 and 5-2).

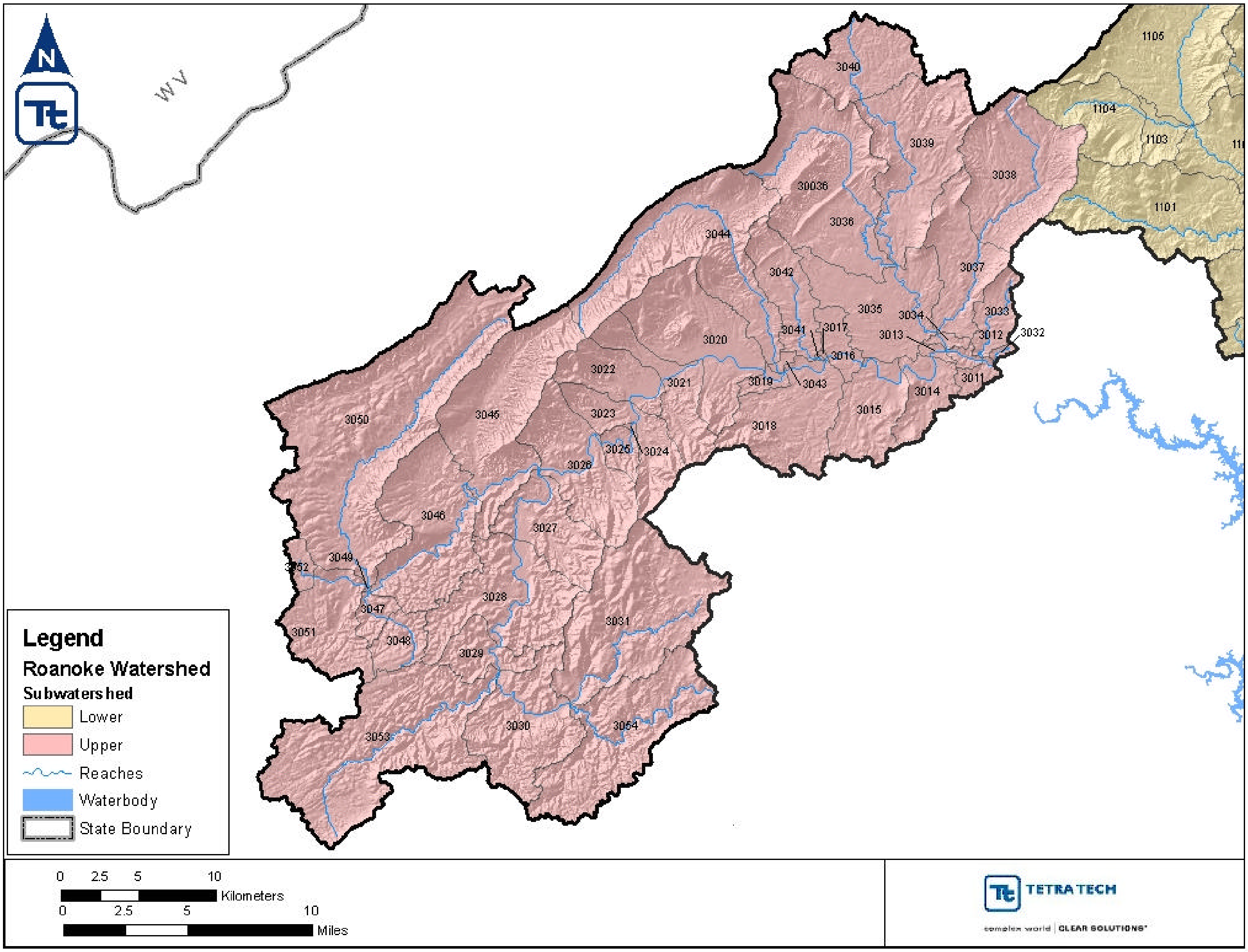

Figure 5-1. Subwatershed divisions of the upper Roanoke.

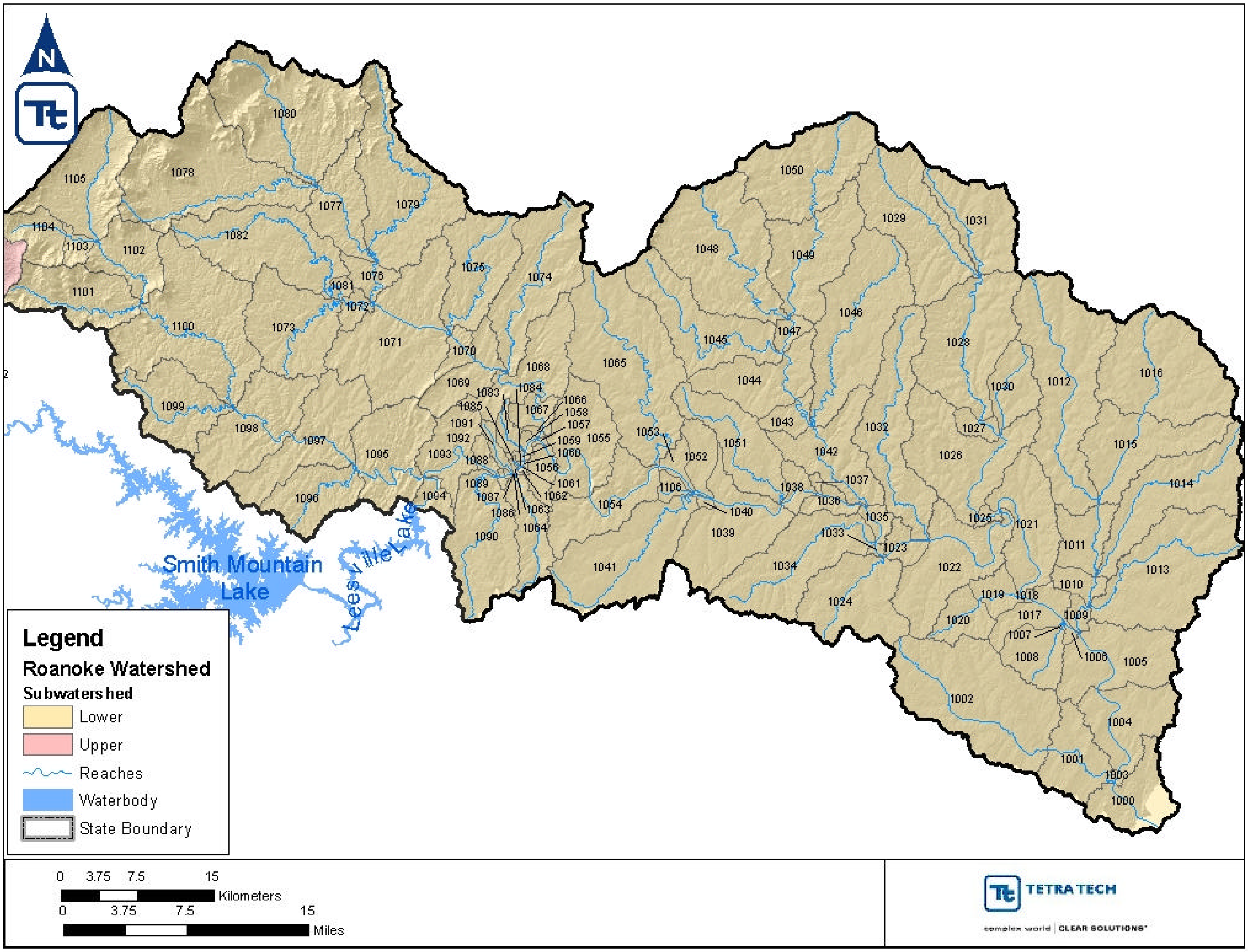

Figure 5-2. Subwatershed divisions of the lower Roanoke (Staunton).

5.2. Configuration of Key Model Components

Configuring the model involved considering three major components, all of which provide the basis for the model's ability to estimate stream flow:

- Meteorological data, which drives the watershed model
- Land use representation, which provides the basis for distributing soils and pollutant loading characteristics throughout the basin
- Watershed physical attributes, which provide the basis for estimating stream channel geometry

5.2.1. Meteorology

Hydrologic processes depend on changes in environmental conditions, particularly weather. As a result, meteorological data are a critical component of the watershed model. These data are the driver of LSPC algorithms simulating watershed hydrology and water quality; thus, accurately representing climactic conditions is required to develop a valid modeling system.

Key meteorological data were accessed from NOAA's National Climatic Data Center (NCDC) to develop a representative data set for the study area covering the modeling period. NCDC stores and distributes weather data gathered by the Cooperative Observer Network (COOP) and Weather Bureau Army-Navy (WBAN) airways stations throughout the United States. COOP stations record hourly or daily rainfall data, while airways stations record various climactic data at hourly intervals, including rainfall, temperature, wind speed, dew point, humidity, and cloud cover.

5.2.2. Land Use and Soils Data

LSPC requires a basis for distributing hydrologic parameters. This is necessary to appropriately represent hydrologic variability throughout the watershed, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly correlated to land practices. The basis for this distribution was provided by land use and soils GIS data coverages for the watershed.

General land use/land cover data sets for the Roanoke River watershed were extracted from the NLCD database (MRLC 2001) (see Section 2.1.1). The land use/land cover data were overlain with the hydrologic soil group data described in Section 2.1.1 to create a composite data layer that describes both land cover and soil group distribution in the watershed (Figure 5-3). The composite layer was used as the model land use allowing for the accurate representation of hydrologic variability at the subbasin level by taking into account both land surface and subsurface characteristics.

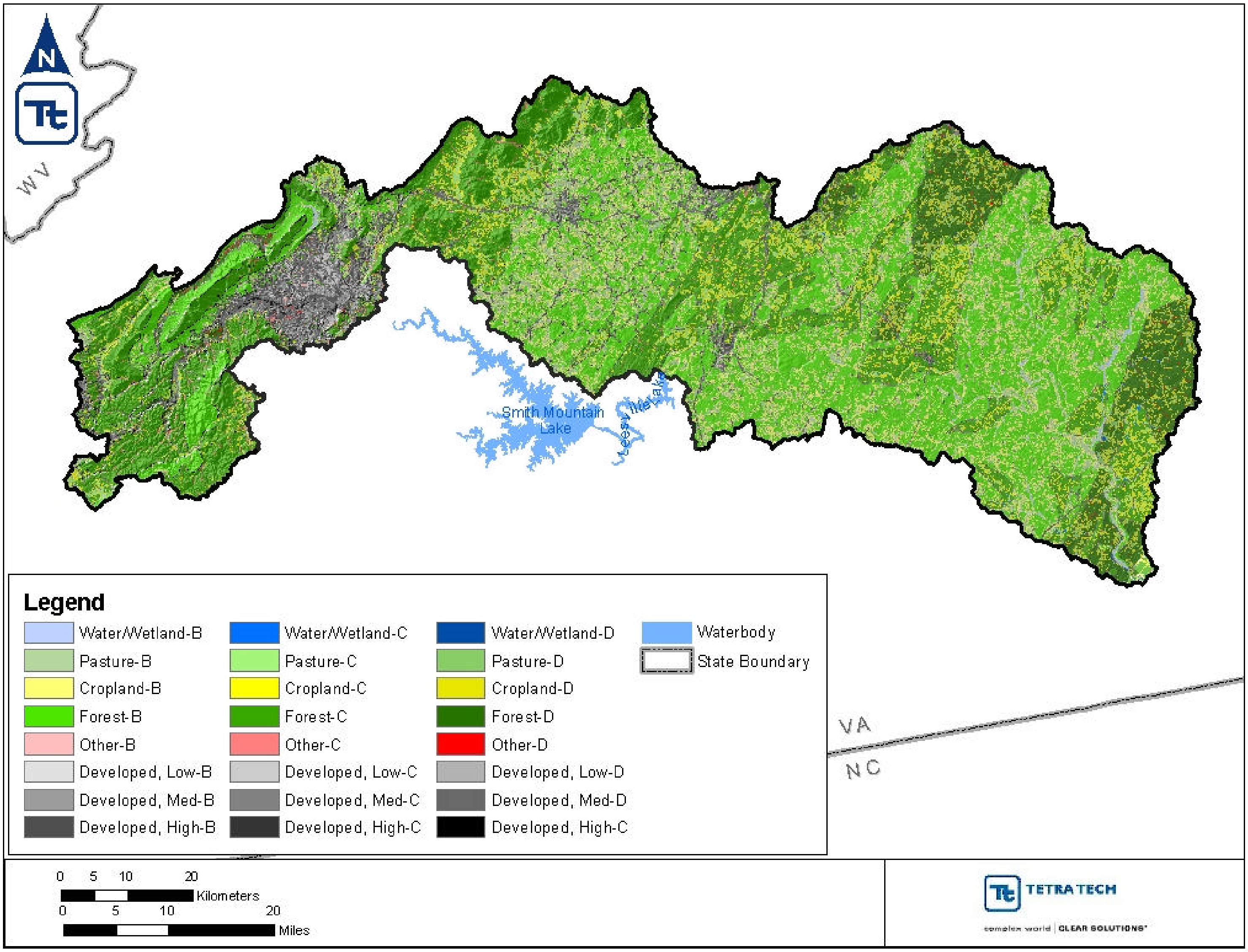

Figure 5-3. Composite model land use.

5.2.3. Elevation Data/Stream Characteristics

LSPC requires a representative stream reach for each subwatershed to route flow throughout the subwatershed network. The stream network connects all the subwatersheds represented in the watershed model. Watershed elevation data derived from the NED (see Section 2.1.3) was used to estimate stream channel slope (USGS 2009).

LSPC requires that each subwatershed-representative stream reach be assigned to a stream class. A stream class defines the model parameters related to the simulation of in-stream pollutant transport and fate processes. A single stream class can be used to define these parameters for all representative stream reaches, or multiple stream classes can be defined in the model allowing parameter variability between stream reaches. For the Roanoke River LSPC model, an individual stream class was defined for each representative stream reach. This approach allowed a unique set of parameters to be assigned to each of the 152 reaches, 107 in the lower and 45 in the upper, corresponding to each model subwatershed.

5.3. Source Representation

The Roanoke River PCB TMDL model considers TSS and PCB sources. Sources of TSS include nonpoint sources associated with the erosion and upland soils washoff and point source discharges from facilities. TSS sources are included in the model setup because the representation of TSS point sources is required to accurately represent watershed hydrology, and nonpoint sediment loadings are the vehicle for sediment-associated PCB loadings.

PCB sources are defined as either current or legacy as described in Section 3.0. Both current and legacy sources are considered by the LSPC model representation of the Roanoke River basin. Current sources are point source dischargers, contaminated sites, urban background including unidentified contaminated sites, and areas covered by general stormwater permits and MS4s. All legacy sources are nonpoint and include in-stream contaminated sediments and atmospheric deposition to surface waters. Available data were plotted in GIS and, as appropriate, assigned to the defined model subbasins, segments, and land uses.

The development of PCB TMDLs in the Roanoke River watershed is subject to adaptive implementation and ongoing source investigation whereby sources of PCB contamination are continuously being reviewed and updated on the basis of the best available information. The following discussion of PCB sources, therefore, should be considered the most up-to-date information at the time of the development of the TMDLs, rather than a complete and final characterization.

5.3.1. TSS Sources

An inventory of discharge monitoring reports (DMRs) for facilities permitted for point source discharges of TSS in the Roanoke River watershed was provided by VADEQ. In the Roanoke River watershed, 52 facilities representing 55 outfalls are permitted for discharging TSS loads. Effluent from such facilities is represented at the rate and concentrations presented in the DMRs, where available, or at design flow and concentration limits where records were unavailable. Tables 5-1 and 5-2 present the National Pollutant Discharge Elimination System (NPDES) IDs, names, receiving water, design flow, and average concentration limit for facilities in the upper and lower model segments, respectively.

Table 5-1. Model TSS point sources—Upper Roanoke model segment

Facility name	NPDES ID	Outfall	Design flow (mgd)	Receiving stream	Avg. conc. limit (mg/L)
Roanoke City - Falling Creek	VA0001465	001	0	Falling Creek	30
Roanoke City - Carvins Cove Water Filtration Plant	VA0001473	001	0	Carvins Creek, unnamed tributary 1	30
Roanoke City - Carvins Cove Water Filtration Plant	VA0001473	002	0	Carvin Creek unnamed tributary 2	30
Roanoke City - Carvins Cove Water Filtration Plant	VA0001473	003	0	Carvin Creek unnamed tributary 2	30
Steel Dynamics	VA0001589	005	0.039	Peters Creek	No limit
Norfolk Southern Railway Co - Shaffers Crossing	VA0001597	002	0	Lick Run unnamed tributary	30
Shawsville Town - Sewage Treatment Plant	VA0024031	001	0.2	South Fork Roanoke River	30
Western Virginia Water Authority Water Pollution Control Plant	VA0025020	001	42	Roanoke River	2.5
Blacksburg Country Club Sewage Treatment Plant	VA0027481	001	0.035	North Fork Roanoke River	30
Montgomery County PSA - Elliston-Lafayette Waste Water Treatment Plant	VA0062219	001	0.25	South Fork Roanoke River	30
Oak Ridge MHP Sewage Treatment Plant	VA0072389	001	0.015	Falling Creek unnamed tributary	30
Roanoke Moose Lodge	VA0077895	001	0.0047	Mason Creek	30
Crystal Springs Water Treatment Plant	VA0091065	001	0.092	Roanoke River	30

Table 5-2. Model TSS point sources—Lower Roanoke (Staunton) model segment

Facility name	NPDES ID	Outfall	Design flow (mgd)	Receiving stream	Avg. conc. limit (mg/L)
Motiva Enterprises LLC - Montvale	VA0001490	001	0.065	South Fork Goose Creek	No limit
Bedford City - Water Treatment Plant	VA0001503	001	0.038	Little Otter River unnamed tributary	30
Dan River, Inc – Brookneal	VA0001538	001	1.326	Roanoke (Staunton) River	No limit
ITG Burlington Industries, LLC, Hurt Plant	VA0001678	001	3.275	Roanoke River	No limit
Appomattox Trickling Filter Plant	VA0020249	001	0.17	Caldwells Creek	30
Altavista - Wastewater Treatment Plant	VA0020451	001	3.6	Roanoke River	30
Bedford County Schools - Liberty High School	VA0020796	001	0.024	Little Otter River unnamed tributary	30
Bedford County Schools - Body Camp Elem. School	VA0020818	001	0.005	Wells Creek unnamed tributary	30
Bedford Co - New London Academy	VA0020826	001	0.006	Buffalo Creek unnamed tributary	30
Bedford Co - Otter River Elem. School	VA0020851	001	0.005	Big Otter River unnamed tributary	30
Bedford County Schools - Thaxton Elem. School	VA0020869	001	0.004	Wolf Creek unnamed tributary	30
Brookneal - Staunton River Lagoon	VA0022241	001	0.078	Roanoke (Staunton) River	45
Brookneal - Falling River Lagoon	VA0022250	001	0.082	Falling River	30
Bedford City - Sewage Treatment Plant	VA0022390	001	2	Little Otter River	30
Halifax County Schools Clays Mill Elem. School	VA0022748	001	0.0072	Mill Branch unnamed tributary	30
DOC Rustburg Correctional Unit 9	VA0023396	001	0.028	Button Creek unnamed tributary	30
Moneta Adult Detention Facility	VA0023515	001	0.021	Mattox Creek unnamed tributary	30
Campbell Co Util and Serv Auth - Rustburg	VA0023965	001	0.2	Molley Creek	30
Keysville Waste Water Treatment Plant	VA0024058	001	0.5	Ash Camp Creek	30
Charlotte County Schools Bacon District Elem. School	VA0029319	001	0.006	Little Horsepen Creek unnamed tributary	30
Charlotte County Schools Phenix Elem. School	VA0029335	001	0.006	Terrys Creek unnamed tributary	30
Briarwood Village Mobile Home Park Sewage Treatment Plant	VA0031194	001	0.024	Smith Branch unnamed tributary	30
BP Products North America Incorporated	VA0054577	001	0	South Fork Goose Creek	No limit
BP Products North America Incorporated	VA0054577	003	0	South Fork Goose Creek unnamed tributary	No limit
Magellan Terminals Holdings LP - Montvale Terminal	VA0055328	001	0.008	South Fork Goose Creek unnamed tributary	No limit
Camp Virginia Jaycees Sewage Treatment Plant	VA0060909	001	0.015	Day Creek unnamed tributary	30
Charlotte County Schools Jeffress Elem. School	VA0063118	001	0.004	Sandy Creek unnamed tributary	30
Southern Mobile Home Park	VA0063568	001	0.0096	Piney Creek unnamed tributary	30
Bedford County Schools - Staunton River High School	VA0063738	001	0.026	Shoulder Run unnamed tributary	30
Thousand Trails Lynchburg Preserve	VA0068543	001	0.0396	Mollys Creek	30
Clover Waste Water Treatment Plant	VA0073733	001	0.035	Clover Creek	30
Woodhaven Nursing Home - Montvale	VA0074870	001	0.005	South Fork Goose Creek unnamed tributary	30
Campbell Co Utility and Service Authority - Otter River Water Filtration Plant	VA0078646	001	0.0428	Big Otter River	30
Alum Springs Shopping Center	VA0078999	001	0.04	Buffalo Creek	30

Facility name	NPDES ID	Outfall	Design flow (mgd)	Receiving stream	Avg. conc. limit (mg/L)
Old Dominion Electric Cooperative Clover	VA0083097	001	1.735	Roanoke River	30
Dominion - Pittsylvania Power Station	VA0083399	001	0.192	Roanoke River	30
Brookneal Town Water Treatment Plant	VA0084034	001	0.0006	Phelps Creek	30
Drakes Branch Waste Water Treatment Plant	VA0084433	001	0.08	Twitty's Creek	30
Montvale Wastewater Treatment Plant	VA0087238	001	0.05	South Fork Goose Creek	30
Dillons Trailer Park - Sewage Treatment Plant	VA0087840	001	0.018	Poorhouse Creek	55
Cedar Rock Waste Water Treatment Plant	VA0091553	001	0.015	Elk Creek unnamed tributary	30
Moneta Regional Waste Water Treatment Plant	VA0091669	001	0.5	Hunting Creek	30

5.3.2. PCB Sources

Current Sources

The 12 point and 21 nonpoint sources described in Section 3.0 are represented as current PCB sources in the model. In addition to the known current sources, urban land areas throughout the model watershed have been assigned a level of contamination on the basis of available sediment monitoring data to account for unidentified contaminated sites. Such areas are referred to as *urban background/unidentified* sources for the purposes of this TMDL.

Nonpoint Sources

The LSPC model was set up to represent nonpoint source loading of PCBs as a sediment-associated process. For the representation of known contaminated sites, a PCB-contaminated land use was created. Using estimates of site footprints and locations, PCB land use areas were assigned to model subbasins. The areas of PCB land uses are shown in Figures 3-2 through 3-4.

Sites known to have PCB-contaminated soils were delineated into parcels as depicted in available aerial photography and USGS topoquads to estimate the contamination footprint. General model land use areas within the footprint were converted to corresponding PCB land uses and assigned a soils tPCBs concentration, or *potency factor*, on the basis of available monitoring data. The soils monitoring data from the literature sources listed in Section 3.1 were used to estimate potency factors for known contaminated sites. A potency factor calculated from available sediment monitoring data was also assigned to the remaining land areas in the watershed to capture loadings from urban background/unidentified contaminated sites. Table 5-3 lists the model-represented known contaminated sites, associated land area, and contamination level. For a discussion of contaminated site contamination levels, see Appendix G.

Table 5-3. Model PCB-contaminated sites

Site name	NPDES ID	County/city	Receiving stream	Area (acres)	Contamination level
A. O. Smith		Campbell	Roanoke (Staunton) River unnamed tributary	7.7	Moderate
Altavista STP	VA0020451	Campbell	Roanoke (Staunton) River	25.6	Moderate
American Viscose Co.		Roanoke City	Roanoke River	81.1	Moderate
Appalachian Power Co. (APCO) Yard		Roanoke City	Roanoke River	0.8	Moderate
BGF Industries[a]		Campbell	Roanoke (Staunton) River unnamed tributary	20.6	High
Burlington Industries-Altavista[a]	VA0001678	Pittsylvania	Sycamore Creek	116.3	Moderate
Dan River, Inc.	VA0001538	Campbell	Roanoke (Staunton) River	37.7	Moderate
Dixie Caverns Landfill	VAD980552095[b]	Roanoke	Roanoke River	38.7	Moderate

Site name	NPDES ID	County/city	Receiving stream	Area (acres)	Contamination level
East town Dump-Altavista		Campbell	Roanoke (Staunton) River	14.5	Moderate
English Construction		Pittsylvania	Roanoke (Staunton) River	12.0	Moderate
Evans Paint	VASFN0305570[b]	Roanoke City	Roanoke River	1.7	Moderate
Jacob Webb		Roanoke City	Roanoke River	5.5	Moderate
Lane Furniture Co.		Campbell	Roanoke (Staunton) River	49.6	Moderate
Norfolk Southern 1		Roanoke City	Roanoke River	2.5	Moderate
Norfolk Southern 2		Roanoke City	Roanoke River	64.3	Moderate
Oil distributors-Altavista		Campbell	Lynch Creek	5.7	Moderate
Roanoke River Floodway Bench Cuts		Roanoke	Roanoke River	47.4	Moderate
Schrader Bridgeport[a]		Campbell	Roanoke (Staunton) River unnamed tributary	16.0	Moderate
Tinker-American Electric Power (AEP) property		Roanoke City	Roanoke River	23.0	Moderate
Virginia Scrap Iron Co.	VRP408 [c]	Roanoke City	Roanoke River	7.0	Moderate
				0.17	High
West town dump-Altavista		Campbell	Lynch Creek	28.0	Moderate

a. Where a contaminated site is covered by a stormwater permit, the source is considered a stormwater site for TMDL purposes (see *Point Sources* in Section 5.3.2)
b. EPA Superfund ID#
c. Virginia Voluntary Remediation Program (VRP) site#

Point Sources

PCB point sources for the TMDLs are traditional facility effluent, MS4s, and sites permitted for stormwater discharges. An inventory of the three types of point sources was provided by VADEQ to be included in the Roanoke River watershed model.

Facilities found to be discharging PCB contaminated effluent as part of the 2005–2008 Special Study monitoring are represented as PCB point sources in the model. In addition, several additional facilities were included as PCB point sources at the request of VADEQ. Facilities represented as PCB point sources and associated information including NPDES ID, mean monthly flow, and model represented effluent PCB concentration are presented in Table 5-4.

Table 5-4. Model PCB point source dischargers

NPDES facility name	Facility type	NPDES ID	Outfall	Mean monthly flow (cfs)	Mean PCB conc. (pg/L)
Dan River, Inc. - Brookneal	Fabrics finishing	VA0001538	001	1.05	500
Steel Dynamics	Steel works	VA0001589	005	0.09	1,090
Norfolk Southern Railway Co - Shaffers Crossing	Railroads, line-haul operating	VA0001597	002	0.01	390
ITG Burlington Industries, LLC - Hurt Plant	Fabrics finishing	VA0001678	001	3.29	19,150
Altavista Town - Wastewater Treatment Plant	Sewerage systems	VA0020451	001	2.39	10,000
Brookneal Town - Staunton River Lagoon	Sewerage systems	VA0022241	001	0.07	140
Montgomery County PSA - Shawsville Sewage Treatment Plant	Sewerage systems	VA0024031	001	0.09	390
Western Virginia Water Authority Water Pollution Control Plant	Sewerage systems	VA0025020	001	57.78	340
Blacksburg Country Club	Sewerage systems	VA0027481	001	0.03	390
Montgomery County PSA - Elliston Lafayette Waste Water Treatment Plant	Sewerage systems	VA0062219	001	0.11	390
Old Dominion Electric Cooperative - Clover	Electric Services	VA0083097	001	1.16	190
Old Dominion Pittsylvania Power Station	Electric Services	VA0083399	001	0.17	140

VADEQ provided an inventory of MS4s and sites and facilities that were issued general permits for stormwater discharges in the Roanoke River basin. Such facilities are not subject to numerical criteria, but have responsibilities related to minimizing stormwater runoff and pollutant loads, and may be subject to monitoring requirements. These areas are not represented explicitly in the model but are assigned PCB WLAs in the TMDL. PCB loads for these areas are estimated as an area-weighted fraction of nonpoint source, land-use contributions.

Modeled land uses were overlain with GIS coverages of MS4s and sites covered by general stormwater permits to characterize the land use distributions of those areas. PCB loads for the permitted areas were calculated as the load generated by their respective land areas. Table 5-5 lists MS4s in the Roanoke River basin. Appendix C provides a list of sites and facilities covered by general stormwater permits. Loads from contaminated sites within the spatial extent of an MS4 or site permitted for stormwater are considered a component of the associated MS4 or general stormwater permit. Where a stormwater permit is located within an MS4, the load is assigned to the stormwater permit.

Table 5-5. MS4s in the Roanoke River watershed

MS4 permit holder	Permit number	Area (acres)
Roanoke County	VAR040022	28,907
City of Roanoke	VAR040004	23,577
Botetourt County	VAR040023	5,180
City of Salem	VAR040010	9,332
Town of Blacksburg	VAR040019	1,613
Town of Christiansburg	VAR040025	1,193

Legacy Sources

Legacy sources represented in the model are PCB contributions from contaminated streambed sediments and background atmospheric deposition of PCBs to surface waters. Those sources exist at an interface with the affected waterbody and can be characterized as nonpoint sources.

Contaminated Streambed Sediments

Streambed sediments can contain significant concentrations of PCBs from historical or current loadings or both. The PCBs can be released to the water column by resuspension of streambed sediments and desorption of PCBs, desorption of PCBs at the streambed-water column interface, and the direct diffusion of PCBs from lower contaminated sediment layers.

The mass of PCBs in streambed sediments available for loading at the beginning of the simulation period is set as an initial condition in the LSPC model setup. It is defined by a sediment tPCBs concentration and streambed depth, density, and porosity assigned to each model-represented stream class. The Roanoke River basin model includes an individual stream class for each model subbasin-representative stream reach, as discussed in Section 5.2.3. Stream classes define critical in-stream parameters including initial sediment pollutant concentration, streambed depth, density, and porosity. Assigning individual stream classes to each subwatershed stream reach allows model parameters to be specific to each reach.

Background Atmospheric Deposition

The net exchange of gas-phase molecules between the atmosphere and a waterbody (dry atmospheric deposition) is a function of the relative concentrations of the chemical in each. There are no available data to characterize the atmospheric and water column concentrations of gaseous PCBs in the Roanoke River watershed. The Chesapeake Bay Program Atmospheric Deposition Study (Chesapeake Bay Program 1999) has estimated a net dry atmospheric deposition rate for urban and regional (nonurban) areas, 16.3 and 1.6 $\mu g/m^2/yr$ tPCBs, respectively (ICPRB 2007). The regional atmospheric deposition rate for tPCBs was incorporated into the Roanoke model as an estimate of local conditions. If local data become available, they will be incorporated into future TMDL studies.

5.4. Model Boundary Condition

The Roanoke River watershed was divided into two separate segments for modeling purposes—the upper Roanoke, which extends from the River headwaters downstream to Niagra Dam, and the lower Roanoke (Staunton), which includes the length of the River from Leesville Dam to its confluence with the Dan River. Because there is no dynamic link between the two, to accurately represent the lower watershed, discharge data for the Leesville Dam, which represents all upstream flows to that point on the river, were incorporated as a model boundary condition.

To account for the PCB loadings from sources in the upper and middle Roanoke, a boundary condition PCB water concentration was assigned to the model-represented Leesville Dam discharge. The boundary water column concentration was estimated from available fish tissue data collected at monitoring station ROA140.66—which is the only monitoring station in Leesville Reservoir—using calculated BAFs for resident fish species. A BAF-converted fish tissue PCB concentration is an estimate of the ambient water quality that captures all upstream source contributions and associated watershed and in-stream processes.

Four fish tissue records were converted into equivalent water column concentrations, giving a concentration range of 40.0–120.0 pg/L and a median concentration of 79.0 pg/L. The median value was assigned as the model boundary condition. That value is significantly lower than the applicable state human health water quality criterion for PCBs (1,700 pg/L) and is indicative of Leesville Reservoir's status as unimpaired for PCBs. Discussion of the methodology for developing and applicability of BAFs is presented in Appendix A.

5.5. Existing Conditions/Model Calibration and Validation

The model was developed in a step-wise manner, beginning with basic watershed processes and building on them to ultimately represent PCB loading and transport. The foundation of the model is simulated hydrology. On the basis of the calibrated hydrology, sediment loading and transport were simulated and calibrated. Watershed hydrology and sediment simulations provide the framework for PCB loadings and transport modeling. The sections that follow discuss briefly the development of each aspect of the watershed model. For a more detailed explanation of each, see Appendix G.

5.5.1. Selecting a Representative Modeling Period

Selecting a representative modeling period was done using the availability of stream flow and water, fish tissue, and sediment monitoring data collected in the Roanoke River watershed that cover varying wet and dry periods. VADEQ has collected water, fish tissue, and sediment monitoring data for the Roanoke River since 1973, but the period of 1990–2008 was selected for modeling purposes. This period includes monitoring results in step with modern analytical methods and includes varying climatic and hydrologic conditions, including dry, average, and wet periods that typically occur in the area.

5.5.2. Hydrology

Hydrology and water quality calibration are performed in sequence, because water quality modeling is dependent on an accurate hydrology simulation. The driver of model hydrology is climatological data, described in Section 5.2.1 and Appendix G. Such data are used as input to simulate the watershed water balance within the LSPC model framework that describes the watershed subbasin network, topology, land use, soils, and reach characteristics.

Hydrology Calibration/Validation

Land use-specific hydrology parameters are used to calibrate modeled hydrology. Calibration involves comparing the modeled and observed flow rates at locations in the watershed where observed data are available. Appendix D presents LSPC Hydrology parameters and the range of values used for the Roanoke River watershed model.

STATSGO served as a starting point for designating infiltration and groundwater flow parameters. Starting values were refined through the hydrologic calibration process. As discussed in Section 5.2.2, a custom land use data layer was developed that accounted for the variability of hydrologic characteristics throughout the watershed. To account for topography variability in the upper and lower Roanoke (Staunton), two groups of land use parameters were configured in the model. This allowed for designating separate hydrology parameter values for the upper and lower segments. Assigning appropriate parameter values was dependent on the composite hydrologic soil group/land cover distribution of each subwatershed.

Average daily flow discharge data were available for eight and seven USGS gages in the upper and lower Roanoke (Staunton) River, respectively (Figure 5-4). The upper Roanoke watershed model was calibrated using daily stream flow data from USGS gages 02056000 and 02053800, while the lower Roanoke (Staunton) was calibrated using gages 02066000 and 02061500. USGS gages 02056000 and 02066000 were selected as calibration points because they represent the farthest downstream locations in the upper and lower sections and capture the distribution of land uses and soil groups in each. An accurate model calibration at these points would capture the overall water budget for the upper and lower Roanoke (Staunton) and reflect the cumulative range of flows for their entire stream networks.

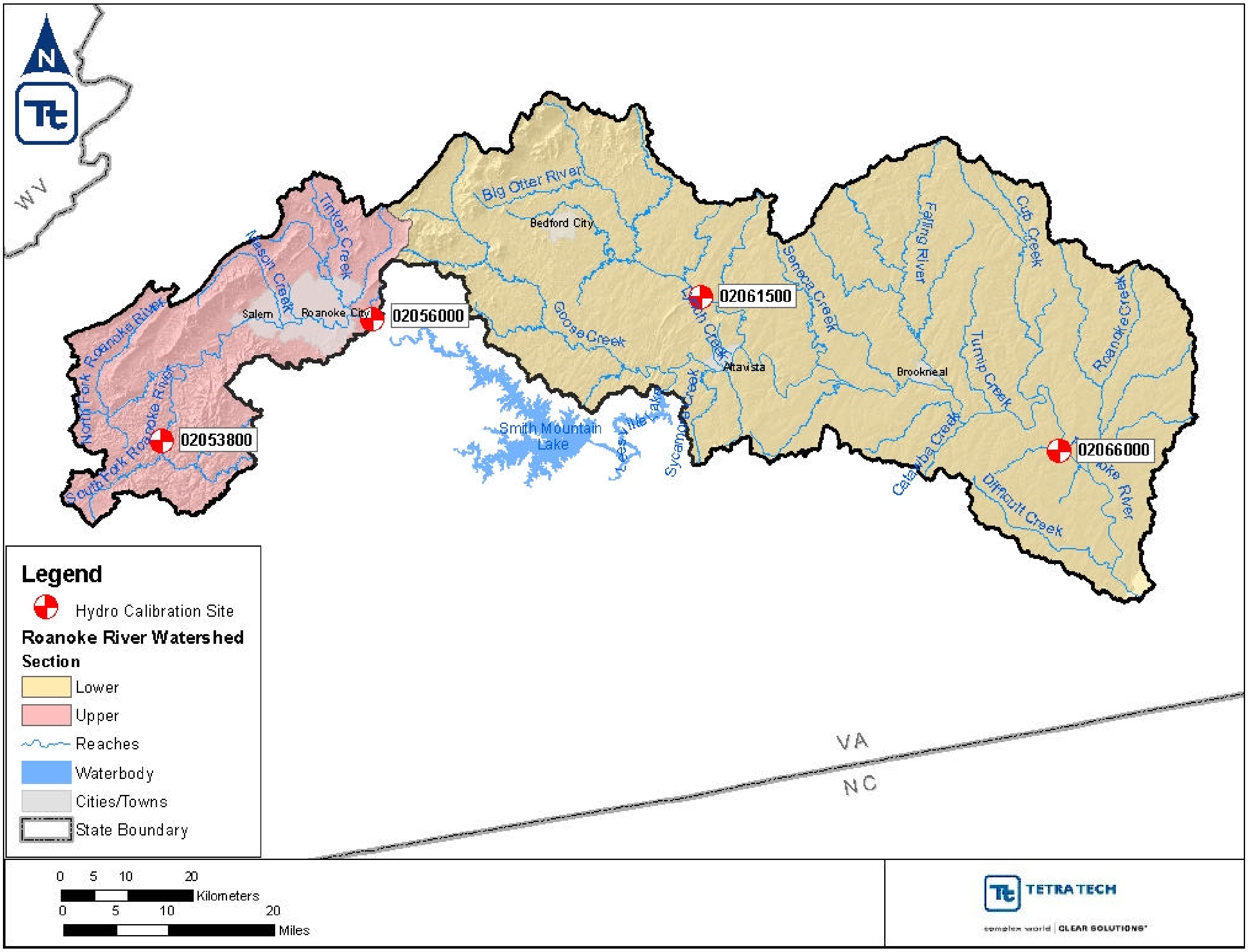

Figure 5-4. Locations of hydrology calibration USGS gages.

USGS gages 02053800 and 02061500 are on tributaries to the upper and lower Roanoke (Staunton)—South Fork Roanoke River and Big Otter River, respectively—and were used as calibration points to verify the applicability of the calibration to smaller areas within watersheds. Agreement between simulated and observed flows at both mainstem and tributary points would suggest an accurate hydrologic system representation of the upper and lower Roanoke (Staunton) watersheds. The USGS gages used for calibration are listed in Table 5-6.

Table 5-6. USGS continuous daily discharge gages used for hydrology calibration

Site ID	Station name	Drainage area (square miles)	Period of record
02053800	South Fork Roanoke River near Shawsville, VA	109	1/1/1990–5/31/2008
02056000	Roanoke River at Niagra, VA	509	1/1/1990–5/31/2008
02061500	Big Otter River near Evington, VA	315	1/1/1990–5/31/2008
02066000	Roanoke (Staunton) River at Randolph, VA	2,966	1/1/1990–5/31/2008

Model calibration years were selected using the following four criteria:

1. Completeness of the weather data available for the selected period
2. Representation of low-flow, average-flow, and high-flow water years
3. Consistency of selected period with key model inputs (i.e., land use coverage)
4. Quality of initial modeled versus observed data correlation

After a review of the data for those four selection criteria, the years 2004 and 1996 were chosen as calibration periods for the upper and lower Roanoke (Staunton), respectively. The NLCD land use coverage used in the model was developed in 2001; therefore, the selected calibration periods are consistent with that key model input. The model was validated for long-term and seasonal representation of hydrologic trends using a period of 18.5 years (January 1, 1991, through May 31, 2008) for both the upper and lower watersheds.

Model calibration was performed using the error statistics criteria specified in HSPEXP, temporal comparisons, and comparisons of seasonal, high flows, and low flows. Calibration involved adjusting infiltration, subsurface storage, evapotranspiration, surface runoff, and interception storage parameters. After adjusting the appropriate parameters within acceptable ranges, good correlations were found between model results and observed data. Hydrology calibration and validation results are presented in Appendix E. It is important to note that although the included log plots allow for comparative visualization of flows that span several orders of magnitude, that type of graph tends to diminish the differences in high flows, while exaggerating the differences in low flows.

Overall, the calibrated model predicted the watershed water budget well. All model validations showed the modeled water budget to be within 9 percent of observed conditions. Predicted seasonal volumes were also within recommended ranges at every location. Predicted storm volumes and storm peaks also closely matched observed data. Because the runoff and resulting stream flow are highly dependent on rainfall, occasional storms were over-predicted or under-predicted depending on the spatial variability of the meteorologic and gage stations.

5.5.3. Sediment

In-stream sediment concentrations are modeled as a function of discrete processes including erosion of soil particles from land areas; transport of eroded sediments to streams; and in-stream transport, scour, and deposition of sediments. Sediment loadings are dependent on hydrologic conditions, particularly the amount and timing of surface runoff, while in-stream processes are dependent on the unique hydraulics of each reach.

Sediment Calibration

Land use and stream class-specific sediment parameters are used to calibrate modeled sediment loading and in-stream processes, respectively. Calibration involves comparing the modeled and observed sediment loads and TSS concentrations at locations in the watershed where observed data are available. Appendix D presents LSPC sediment parameters and the range of values used for the Roanoke River watershed model.

Sediment land use parameters are closely related to the factors of the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978), which served as a starting point for designating related soil detachment and washoff parameters. Appropriate values were assigned to the composite land use on the basis of the land cover description and hydrologic soil group. Starting values were refined through the sediment calibration process. Event mean concentrations were also defined to represent background concentrations not captured by the discrete erosive processes simulated by the model, particularly for low-flow conditions. All sediments and soils represented in the model are assigned particle class fractions (e.g. % sand, silt, clay). Analysis of the distribution of STATSGO soil groups in the watershed was used to estimate the particle class fractions of eroded upland soils.

In-stream sediment parameters are based primarily on the physical properties of the particle class fractions including particle diameter, fall velocity, and density. Such properties were estimated from the range of literature values presented in *EPA BASINS Technical Note 8, Sediment Parameter and Calibration Guidance for HSPF* (USEPA 2006).

Observed TSS data are available for 21 and 43 monitoring stations in the upper and lower Roanoke (Staunton), respectively. On the basis of the number of data records and co-location with USGS continuous flow gages, the Roanoke River watershed model was calibrated for sediment using TSS monitoring stations ROA227.42, ROA204.76, ROA97.46, and ROA67.91 (Figure 5-5). Stations at river mile 227.42 and 204.76 are in the upper Roanoke model segment, while stations at river mile 97.46 and 67.91 are in the lower Roanoke (Staunton) model segment. General descriptions of these monitoring locations are presented in Table 5-7.

Table 5-7. TSS monitoring station used for TSS calibration

Station ID	Station description	Period of record	Associated flow gage
4AROA067.91	Rt.746 bridge (Watkina Bridge) near Randolph, VA	2/1/1990–9/10/2007	USGS 02066000
4AROA097.46	Roanoke River at Brookneal gage, Rt. 50	1/24/1990–5/1/2007	USGS 02062500
4AROA204.76	Roanoke River at Roanoke City, VA	10/13/2005–11/22/2005	USGS 02055000
4AROA227.42	Rt. 773 at gaging station in Lafayette, VA	1/10/1990–5/9/2007	USGS 02054500

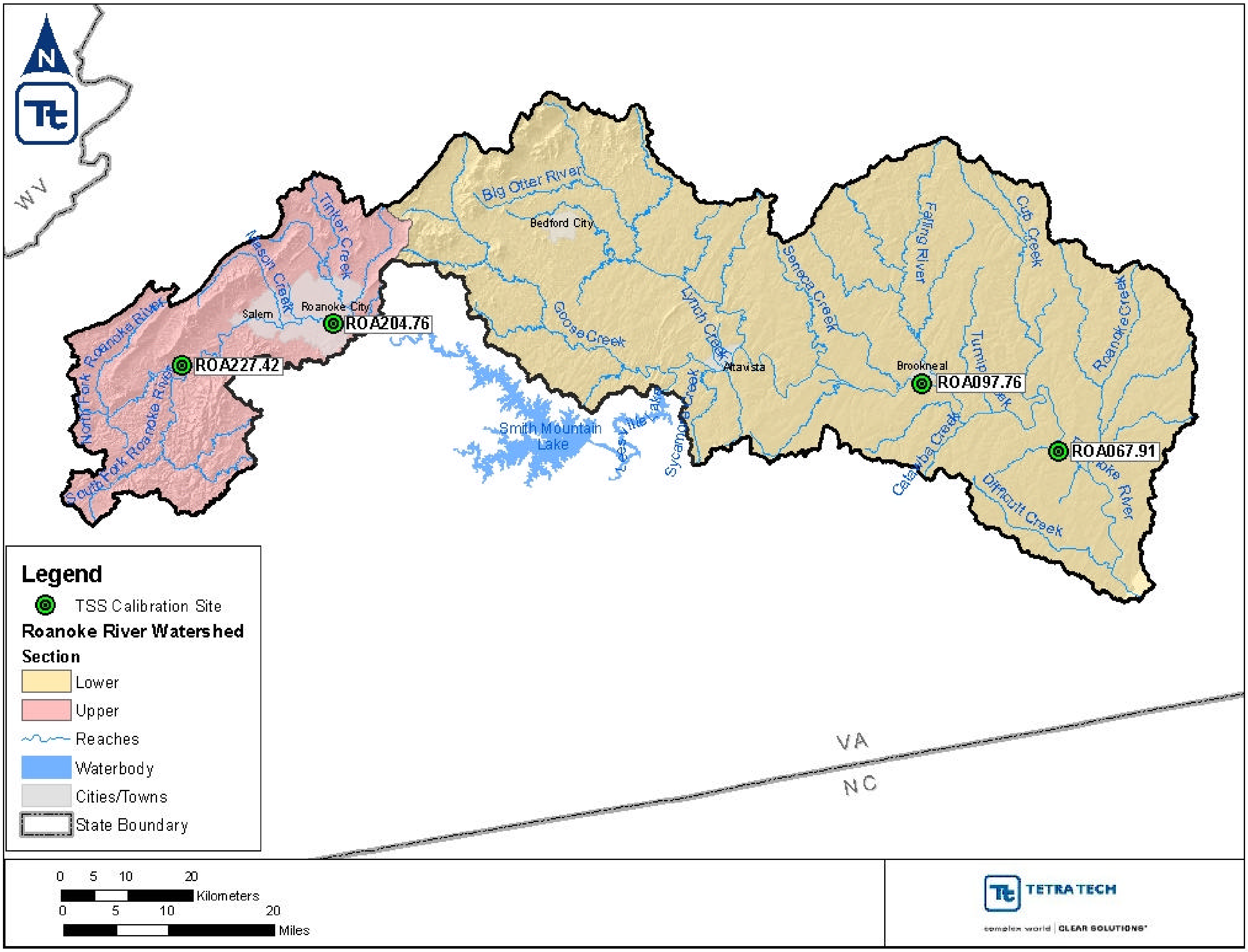

Figure 5-5. Locations of TSS monitoring calibration stations.

Sediment simulations were run for the model time series as described in Section 5.5.1. Antilog plots of flow versus sediment loads for observed and modeled data are presented for the selected calibration locations in Appendix F. In general, the magnitude of sediment loadings for observed and modeled data increase at a similar rate and are within the same range for the gradient of flow conditions. Observed loadings are, generally, more variable in relation to flow conditions than in modeled scenarios. Log plots comparing model output to observed TSS concentrations at the selected locations are also presented in Appendix F. Note that observed concentrations reported as detection limits have been assigned a concentration of 3 mg/L.

5.5.4. PCBs

LSPC was configured to simulate tPCBs in both the dissolved- and sediment-associated states to characterize water quality conditions in the Roanoke River watershed. The simulation of loadings and in-stream behavior of tPCBs as a sediment-associated pollutant is dependent on the hydrologic and TSS calibrations that serve as its foundations.

The model was set up to represent a unique stream class for each subwatershed stream reach as discussed in Section 5.2.3. Each model stream class defines critical in-stream parameters, including the conditions related to the mass balance of tPCBs for the sediment-water system in each stream reach. tPCBs are partitioned into dissolved and particulate fractions in both the water (PCB with suspended sediment interaction) and sediment layers (PCB with bed sediment interaction). LSPC simulates deposition (settling) and scour (resuspension) of PCBs with sediment in addition to sorption/desorption and in-stream losses.

PCB Calibration

Land use and stream class-specific PCB parameters are used to calibrate modeled tPCB loading and in-stream processes, respectively. Calibration involves comparing the modeled and observed tPCB concentrations at locations in the watershed where observed data are available. Appendix D presents LSPC PCB parameters and the range of values used for the Roanoke River watershed model.

Monitoring data collected by VADEQ were used to define the model's design and representation of critical parameters required for simulating tPCBs in each stream class. Such parameters include the following:

- Particle class fractions of upland soils and streambed sediments
- The initial tPCBs concentration of particle class fractions
- Partition coefficients as a function of the fraction of the organic carbon content in stream sediments and homolog composition of PCB contamination
- Adsorption/desorption rates as a function of the homolog composition of PCB-contaminated suspended sediments

Observed water column tPCB data are available for 29 monitoring stations throughout Roanoke River watershed. These stations were sampled as part of the 2005–2008 PCB monitoring special study conducted by VADEQ (see Section 2.3). On the basis of the confidence in the analytical results of the sampling data, the Roanoke River watershed model was calibrated at the 24 PCB monitoring stations shown in Figures 5-6 and 5-7. General descriptions of the monitoring locations are presented in Table 5-8.

Table 5-8. PCB monitoring stations used for PCB calibration

Monitoring station	Station description	Sample dates
4ADFF002.02	Difficult Creek at Rt. 716	8/28/07
4AROA059.12	Roanoke River near Rt. 360 - Clover	9/10/07, 10/26/07
4ABWC001.00	Black Walnut Creek	10/26/07
4AROC001.00	Roanoke Creek near Saxe	8/28/07, 10/26/07
4AROA067.91	Roanoke River near Rt. 746	9/10/07, 10/26/07
4ACUB002.21	Cub Creek at Rt. 649 (Coles Ferry Road)	8/28/07, 10/26/07
4AROA090.50	Roanoke River at Rt. 620 South of Brookneal	8/8/07, 10/26/07
4AROA097.76	Roanoke River upstream of Brookneal	8/8/07, 3/6/08
4AFRV002.78	Falling River downstream of lagoon outfall	9/10/07
4AROA108.09	Roanoke River near Long Island	9/10/07
4AROA124.59	Roanoke River downstream Altavista	3/10/08, 5/9/08
4AROA127.79	Roanoke River downstream of Altavista STP	8/9/07
4ABOR000.62	Big Otter River at Rt. 712	8/21/07, 10/26/07
4AXLN000.00	Unnamed trib on BGF property	12/1/07
4AROA129.55	Roanoke River near business Rt. 29 bridge at USGS gage	8/8/07, 10/26/07, 5/9/08
4ASCE000.26	Sycamore Creek near Pocket Road	8/27/07

Monitoring station	Station description	Sample dates
4ALYH000.17	Lynch Creek at Riverside Park	5/9/08
4AROA131.55	Rt. 29 Bridge bypass, Altavista	8/8/07, 5/9/08
4AGSE000.20	Goose Creek	9/10/07, 10/26/07
4AROA199.20	Roanoke River just upstream Niagara Dam	3/3/08, 4/7/08
4AROA204.76	Roanoke River at Walnut Ave. in Roanoke City	3/3/08, 4/7/08
4AROA207.08	Roanoke River at Memorial Bridge	3/3/08, 4/7/08
4AROA212.17	419 Bridge near Lewis Gale	3/3/08, 4/7/08
4AROA227.42	Rt. 773 at gaging station in Lafayette	3/3/08, 4/7/08

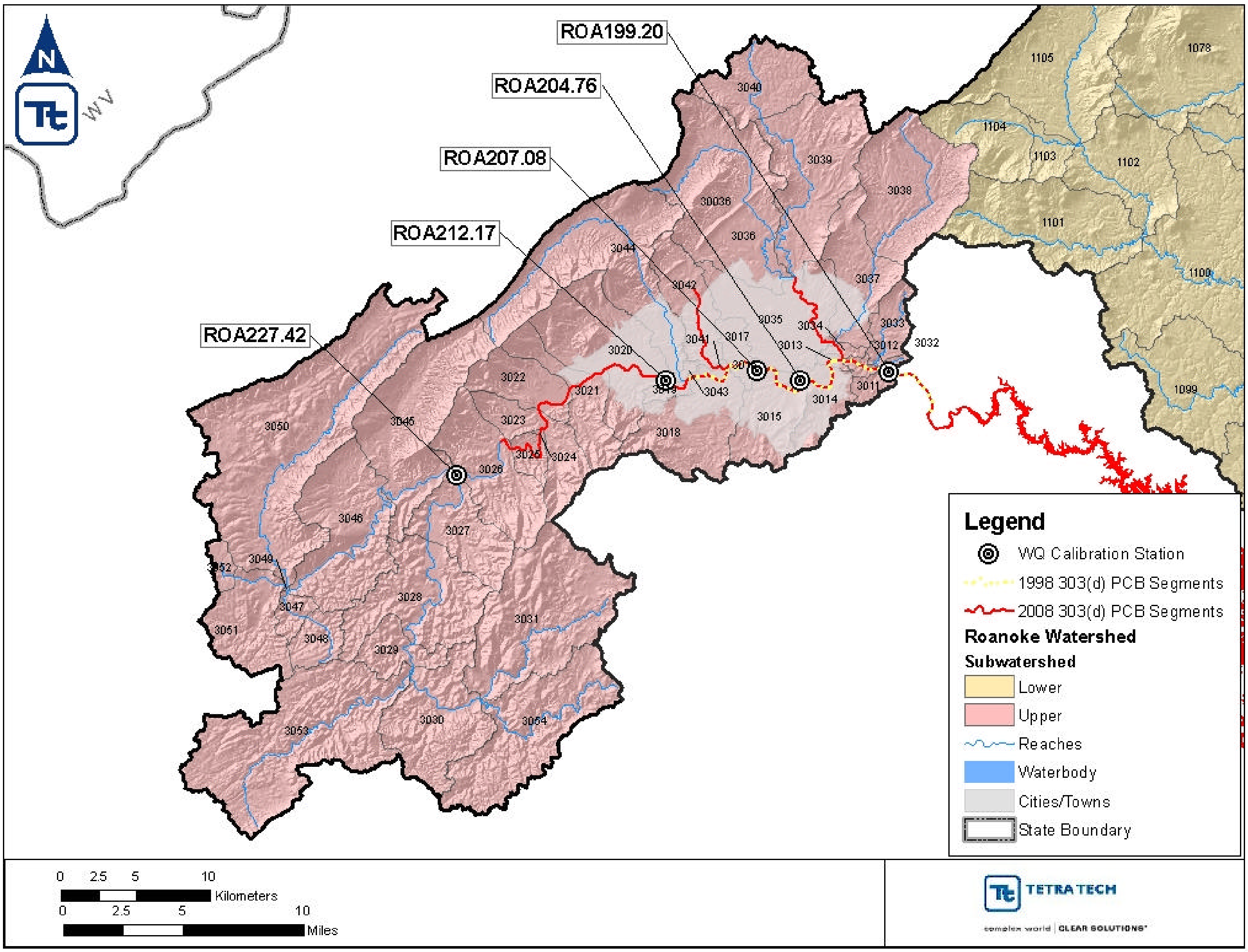

Figure 5-6. Locations of upper Roanoke tPCB-monitoring calibration stations.

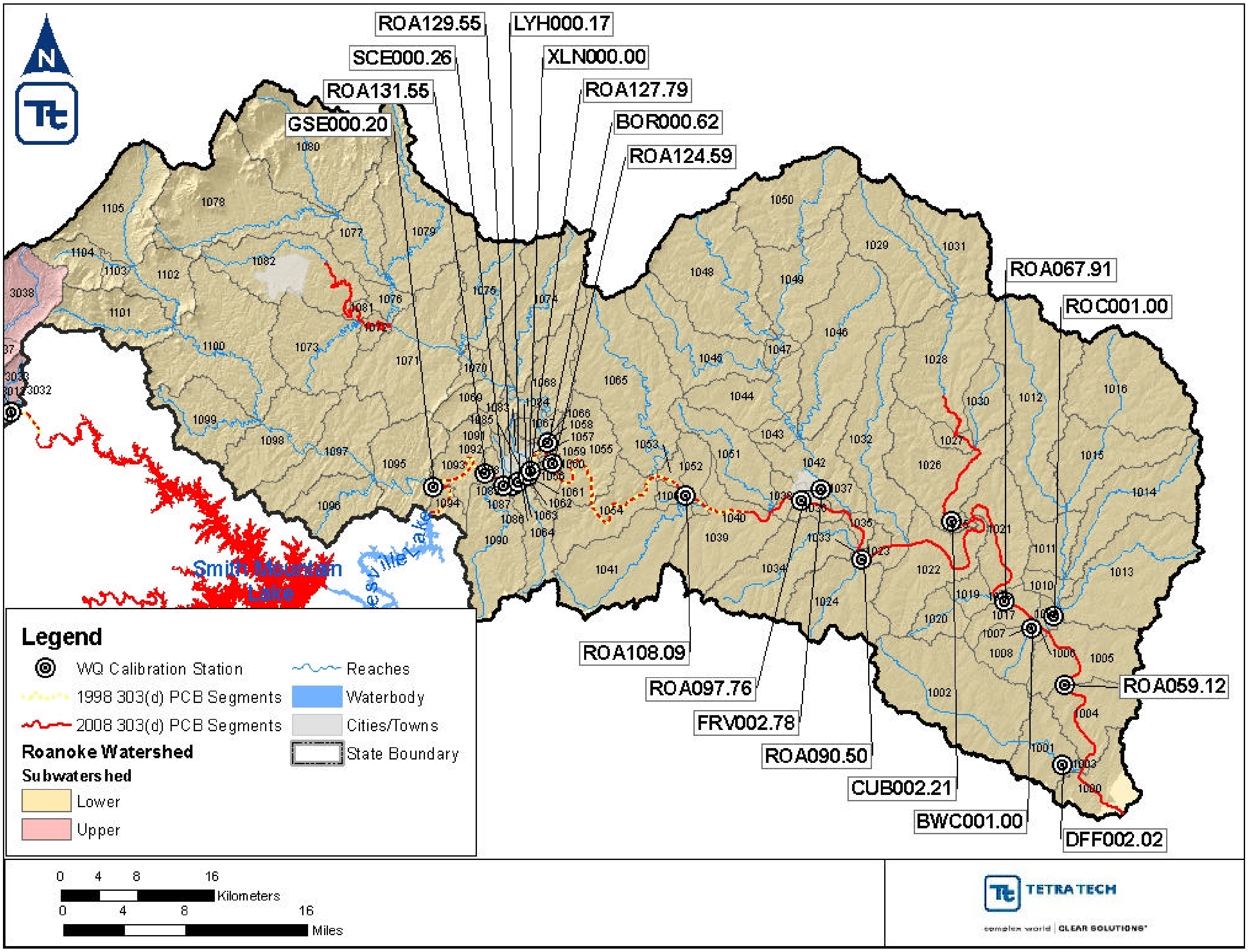

Figure 5-7. Locations of lower Roanoke (Staunton) tPCB-monitoring calibration stations.

PCB simulations were run for the model time series as described in Section 5.5.1. Log plots for observed and modeled tPCBs are presented at the selected calibration locations in Appendix F. In general, the model captures the trends and magnitude of contamination observed in the monitoring data.

At locations with significant upstream contaminated sources and high in-stream shear stresses, storm events cause in-stream concentration spikes as contaminated soils are transported to streams and contaminated streambed sediments are resuspended, releasing associated PCBs. In areas where there are few or no contaminated sites or streambed sediments, storm events cause in-stream tPCBs concentrations to decrease as clean inflows dilute the PCB concentrations directly fluxing from streambed sediments and atmospheric deposition. Finally, in areas where there are highly contaminated streambed sediments and relatively low in-stream shear stresses, the direct flux of PCBs from streambed sediments dominate water column concentrations, whereby storm events cause in-stream tPCBs concentrations to decrease even though there could be significant areas of upstream contaminated soil.

In addition, the magnitude of modeled low-flow and high-flow tPCBs concentrations are generally within the same magnitude as the observed data. This suggests that upland soils contamination areas and PCB concentrations, initial streambed sediment PCB concentrations, and water column-streambed sediment dynamics are being represented appropriately.

6. TMDL ALLOCATION ANALYSIS

A TMDL is the total amount of pollutant that can be assimilated by the receiving waterbody while still achieving water quality standards or goals. It is composed of the sum of individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for both nonpoint sources and background levels. In addition, the TMDL must include a margin of safety (MOS), either implicitly or explicitly, to account for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. Conceptually, this definition is represented by the following equation:

$$\text{TMDL} = \Sigma WLAs + \Sigma LAs + MOS$$

In TMDL development, allowable loadings from pollutant sources are established and when summed, are equivalent to the TMDL which forms the basis for the requirement of water quality-based controls. TMDLs can be expressed on a mass loading basis (e.g., grams of pollutant per day) or as a concentration in accordance with 40 CFR 130.2(l).

The goal of the model application was to determine allowable source contributions that meet the targeted tPCBs water quality TMDL endpoints specific to the upper and lower sections of the watershed. Boundary conditions and source inputs were adjusted to achieve in-stream whole water column tPCBs concentrations that meet the TMDL targets of 390 and 140 pg/L for the upper and lower sections, respectively. Baseline loads represent the existing condition where no load reductions have been applied to the source categories. WLAs and LAs were assigned on the basis of meeting the assimilative capacity of each subwatershed drainage area delineated for the Roanoke River watershed.

Sources were reduced to meet the TMDL endpoints in the worst case scenario subwatersheds in each watershed section. The worst case scenario subwatersheds were 3013 and 1000, both representing the Roanoke River mainstem in the upper and lower Roanoke (Staunton) sections, respectively (See Figures 5-1 and 5-2). Source reductions started with the current sources (point sources and contaminated sites) that can be reasonably reduced, followed by reductions to legacy sources where eliminating current sources was not sufficient to meet the TMDL. The WLAs, LAs, and TMDLs that follow are presented by stream/river segments in the watershed. The model subbasins associated with watershed streams are presented in Table D-8 in Appendix D.

Tables 6-1 and 6-2 present a summary of the WLAs, LAs, and TMDLs, developed for streams in the upper and lower watershed sections on an average annual and daily basis, respectively. As tPCBs bioaccumulate in fish tissue over time, it is more appropriate to express the loads on an annual basis. WLAs and LAs were assigned on the basis of the assimilative capacity of the Roanoke River watershed. Source load allocations for this TMDL scenario are presented in the following sections. Source loads are calculated as the average annual load produced by a source category as simulated in the LSPC model (see Chapter 5 and Appendix G). Average daily loads were calculated as the average annual load divided by 365.

Loadings from contaminated streambed sediments have been excluded from the TMDLs. The rationale for this exclusion is due to the dynamic relationship between the sediment and water column tPCB processes where the flux from sediments is a function of tPCBs concentrations in the stream water-sediment system as a whole (see Appendix G). Rather than a direct loading, the flux of tPCBs to-and-from streambed sediments can be characterized as an internal model mechanism. For this reason the loadings are not comparable to the direct loads contributed by the other sources. Table D-7 in Appendix D presents the initial streambed sediment concentration reductions applied to meet the TMDL condition in the upper and lower Roanoke (Staunton) subwatersheds.

Table 6-1. Average annual tPCBs TMDLs for Roanoke River watershed streams

Stream	2008 303(d) list ID	Baseline (mg/yr)	WLA (mg/yr)	LA (mg/yr)	MOS (mg/yr)	TMDL (mg/yr)	% Reduction
Upper Roanoke River							
North Fork Roanoke River	Not listed	4,923.2	28.2	630.3	34.7	693.2	85.9
South Fork Roanoke River	Not listed	3,532.2	230.2	788.6	53.6	1,072.5	69.6
Masons Creek	Not listed	1,777.5	9.1	193.2	10.6	212.9	88.0
Peters Creek	L12L-01-PCB	1,742.6	65.4	31.2	5.1	101.7	94.2
Tinker Creek	L12L-01-PCB	16,593.6	103.9	3,414.2	185.2	3,703.2	77.7
Wolf Creek	Not listed	1,078.4	10.0	20.3	1.6	31.9	97.0
Unnamed Trib to Roanoke River	Not listed	59.4	0.5	1.3	0.1	1.9	96.8
Roanoke River	L12L-01-PCB	133,207.2	28,157.7	3,455.7	1,663.9	33,277.3	75.0
Upper Total		**162,914.1**	**28,605.0**	**8,534.8**	**1,954.7**	**39,094.5**	**76.0**
Lower Roanoke (Staunton) River							
Goose Creek	Not listed	5,400.9	0.1	1,812.4	95.4	1,907.9	64.7
Sycamore Creek	Not listed	93,226.4	1.4	186.3	9.9	197.6	99.8
Lynch Creek	Not listed	7,670.6	0.1	17.8	0.9	18.8	99.8
Reed Creek	Not listed	274.7	35.3	75.9	5.9	117.1	57.4
X-trib	Not listed	215,127.2	0.1	1.3	0.1	1.5	100.0
Unnamed Trib to Roanoke River	Not listed	12,848.6	0.1	19.1	1.0	20.2	99.8
Little Otter River	L26R-01-PCB	3,934.3	0.0	596.2	31.4	627.6	84.0
Big Otter River	Not listed	7,630.9	0.0	2,462.8	129.6	2,592.4	66.0
Straightstone Creek	Not listed	464.8	0.0	279.0	14.7	293.7	36.8
Seneca Creek	Not listed	692.9	0.0	400.8	21.1	421.9	39.1
Whipping Creek	Not listed	398.4	0.0	157.7	8.3	166.0	58.3
Falling River	Not listed	4,135.2	0.0	1,746.5	91.9	1,838.4	55.5
Childrey Creek	Not listed	390.2	0.0	201.3	10.6	211.9	45.7
Catawba Creek	Not listed	168.8	0.0	94.8	5.0	99.8	40.9
Turnip Creek	Not listed	376.2	0.0	272.6	14.3	286.9	23.7
Hunting Creek	Not listed	86.6	0.0	65.2	3.4	68.6	20.7
Cub Creek	L19R-01-PCB	1,376.7	0.0	997.4	52.5	1,049.9	23.7
Black Walnut Creek	Not listed	181.9	0.8	46.5	2.5	49.7	72.7
Roanoke Creek	Not listed	2,446.8	0.0	1,429.6	75.2	1,504.8	38.5
Difficult Creek	Not listed	823.2	0.0	462.1	24.3	486.5	40.9
Roanoke River	L19R-01-PCB	239,164.0	1,874.9	11,961.7	728.2	14,564.9	93.9
Lower Total		**596,819.2**	**1,912.7**	**23,287.1**	**1,326.3**	**26,526.1**	**95.6**

Table 6-2. Average daily tPCBs TMDLs for Roanoke River watershed streams

Stream	2008 303(d) list ID	Baseline (mg/d)	WLA (mg/d)	LA (mg/d)	MOS (mg/d)	TMDL (mg/d)	% Reduction
Upper Roanoke River							
North Fork Roanoke River	Not listed	13.488	0.077	1.727	0.095	1.899	85.9
South Fork Roanoke River	Not listed	9.677	0.631	2.161	0.147	2.938	69.6
Masons Creek	Not listed	4.870	0.025	0.529	0.029	0.583	88.0
Peters Creek	L12L-01-PCB	4.774	0.179	0.086	0.014	0.279	94.2
Tinker Creek	L12L-01-PCB	45.462	0.285	9.354	0.507	10.146	77.7
Wolf Creek	Not listed	2.955	0.027	0.056	0.004	0.087	97.0
Unnamed Trib to Roanoke River	Not listed	0.163	0.001	0.004	0.000	0.005	96.8
Roanoke River	L12L-01-PCB	364.951	77.144	9.468	4.559	91.171	75.0
Upper Total		**446.340**	**78.370**	**23.383**	**5.355**	**107.108**	**76.0**
Lower Roanoke (Staunton) River							
Goose Creek	Not listed	14.797	0.000	4.966	0.261	5.227	64.7
Sycamore Creek	Not listed	255.415	0.004	0.510	0.027	0.541	99.8
Lynch Creek	Not listed	21.015	0.000	0.049	0.003	0.051	99.8
Reed Creek	Not listed	0.752	0.097	0.208	0.016	0.321	57.4
X-trib	Not listed	589.389	0.000	0.004	0.000	0.004	100.0
Unnamed Trib to Roanoke River	Not listed	35.202	0.000	0.052	0.003	0.055	99.8
Little Otter River	L26R-01-PCB	10.779	0.000	1.633	0.086	1.719	84.0
Big Otter River	Not listed	20.906	0.000	6.747	0.355	7.102	66.0
Straightstone Creek	Not listed	1.273	0.000	0.764	0.040	0.805	36.8
Seneca Creek	Not listed	1.898	0.000	1.098	0.058	1.156	39.1
Whipping Creek	Not listed	1.092	0.000	0.432	0.023	0.455	58.3
Falling River	Not listed	11.329	0.000	4.785	0.252	5.037	55.5
Childrey Creek	Not listed	1.069	0.000	0.552	0.029	0.581	45.7
Catawba Creek	Not listed	0.463	0.000	0.260	0.014	0.273	40.9
Turnip Creek	Not listed	1.031	0.000	0.747	0.039	0.786	23.7
Hunting Creek	Not listed	0.237	0.000	0.179	0.009	0.188	20.7
Cub Creek	L19R-01-PCB	3.772	0.000	2.733	0.144	2.876	23.7
Black Walnut Creek	Not listed	0.498	0.002	0.127	0.007	0.136	72.7
Roanoke Creek	Not listed	6.704	0.000	3.917	0.206	4.123	38.5
Difficult Creek	Not listed	2.255	0.000	1.266	0.067	1.333	40.9
Roanoke River	L19R-01-PCB	655.244	5.137	32.772	1.995	39.904	93.9
Lower Total		**1,635.121**	**5.240**	**63.800**	**3.634**	**72.674**	**95.6**

6.1. Wasteload Allocations

Federal regulations (40 CFR 130.7) require TMDLs to include individual WLAs for each point source. WLAs contain the allowable loadings from existing and future point sources. The WLA portion of the TMDL includes the traditional point source discharges, individually permitted stormwater dischargers, and MS4s. WLAs for point source categories in Roanoke River watershed streams grouped by watershed section are presented in Table 6-3. WLA's for individual point sources, permitted stormwater dischargers, and MS4s are presented in Tables 6-4 through 6-6. Note that the loads calculated for all WLA sources are estimates. Loads assigned to traditional point sources were derived from one or two samples of effluent tPCBs concentrations and loads attributed to stormwater dischargers and MS4s are based on estimates of upland soil tPCBs concentrations (see Appendix G). In all cases additional PCB monitoring will have to be performed.

For this TMDL, the VADEQ agreed to apply a consistent approach to all traditional point sources for determining WLAs. The allocations are derived as facility design flow multiplied by the applicable watershed section water column target. In some cases, because current flows are less than facility design flows, this approach results in a TMDL WLA that is larger than the estimated baseline load, which is indicated by negative reduction values in Table 6-4. In addition, for one point source, VA0025020 Western Virginia Water Authority, the existing concentration at which it is discharging is lower than the applicable water quality target. This also contributed to its negative reduction value.

Table 6-3. Average annual tPCBs WLAs for Roanoke River watershed streams

Stream	Point sources			Stormwater dischargers[a]			MS4s		
	Baseline (mg/yr)	WLA (mg/yr)	% Reduction	Baseline (mg/yr)	WLA (mg/yr)	% Reduction	Baseline (mg/yr)	WLA (mg/yr)	% Reduction
Upper Roanoke River									
North Fork Roanoke River	10.7	18.7	-75.0	105.5	1.1	99.0	990.5	9.9	99.0
South Fork Roanoke River	68.4	240.6	-251.6	0.0	0.0	0.0	177.4	1.8	99.0
Masons Creek	0.0	0.0	0.0	5.9	0.1	99.0	950.6	9.5	99.0
Peters Creek[b]	90.7	53.5	41.1	1.4	0.0	99.0	1,542.2	15.4	99.0
Tinker Creek[b]	0.0	0.0	0.0	81.7	0.8	99.0	10,853.2	108.5	99.0
Wolf Creek	0.0	0.0	0.0	0.0	0.0	0.0	1,053.7	10.5	99.0
Unnamed Trib to Roanoke River	0.0	0.0	0.0	0.0	0.0	0.0	52.8	0.5	99.0
Roanoke River[b]	17,495.9	29,442.0	-68.3	6,579.0	3.1	100.0	94,055.7	194.5	99.8
Upper Total	**17,665.8**	**29,754.8**	**-68.4**	**6,773.5**	**5.1**	**99.9**	**109,676.3**	**350.7**	**99.7**
Lower Roanoke (Staunton) River									
Goose Creek	0.0	0.0	0.0	0.0	0.0	0.0	11.7	0.1	99.3
Sycamore Creek	0.0	0.0	0.0	92,387.5	1.5	100.0	0.0	0.0	0.0
Lynch Creek	0.0	0.0	0.0	8.2	0.1	99.3	0.0	0.0	0.0
Reed Creek	21.3	37.2	-74.7	0.0	0.0	0.0	0.0	0.0	0.0
X-trib	0.0	0.0	0.0	208,892.4	0.1	100.0	0.0	0.0	0.0
Unnamed Trib to Roanoke River	0.0	0.0	0.0	3,885.9	0.1	100.0	0.0	0.0	0.0
Little Otter River[c]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Big Otter River	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Straightstone Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Seneca Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Whipping Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Falling River	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Childrey Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Catawba Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Turnip Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hunting Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cub Creek[d]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Black Walnut Creek	0.0	0.0	0.0	112.1	0.8	99.3	0.0	0.0	0.0

Stream	Point sources			Stormwater dischargers[a]			MS4s		
	Baseline (mg/yr)	WLA (mg/yr)	% Reduction	Baseline (mg/yr)	WLA (mg/yr)	% Reduction	Baseline (mg/yr)	WLA (mg/yr)	% Reduction
Roanoke Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Difficult Creek	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Roanoke River[d]	78,262.0	1,968.3	97.5	82,721.0	5.4	100.0	0.0	0.0	0.0
Lower Total	**78,283.3**	**2,005.5**	**97.4**	**388,007.2**	**7.9**	**100.0**	**11.7**	**0.1**	**99.3**

a. Stormwater loads were assigned to streams based on the spatial orientation of the permitted area within the subbasin network
b. 2008 303(d) segment L12L-01-PCB
c. 2008 303(d) segment L26R-01-PCB
d. 2008 303(d) segment L19R-01-PCB

Table 6-4. Point source tPCBs WLAs

Stream	NPDES ID	Facility	Outfall Number	Baseline (mg/yr)	WLA (mg/yr)	% Reduction
Upper Roanoke River						
North Fork Roanoke River	VA0027481	Blacksburg Country Club	001	10.7	18.7	-75.0
North Fork Roanoke River Total				**10.7**	**18.7**	**-75.0**
South Fork Roanoke River	VA0062219	Montgomery County PSA - Elliston Lafayette WWTP	001	38.5	133.7	-247.0
South Fork Roanoke River	VA0024031	Montgomery County PSA - Shawsville STP	001	29.9	106.9	-257.5
South Fork Roanoke River Total				**68.4**	**240.6**	**-251.6**
Peters Creek	VA0001589	Steel Dynamics	005	90.7	53.5	41.1
Peters Creek Total[a]				**90.7**	**53.5**	**41.1**
Roanoke River	VA0025020	Western VA Water Authority	001	17,491.1	29,404.6	-68.1
Roanoke River	VA0001597	Norfolk Southern Railway Co - Shaffers Crossing	002	4.8	37.4	-681.1
Roanoke River Total[a]				**17,495.9**	**29,442.0**	**-68.3**
Upper Total				***17,665.8***	***29,754.8***	***-68.4***
Lower Roanoke (Staunton) River						
Reed Creek	VA0083399	Old Dominion Pittsylvania Power Station	001	21.3	37.2	-74.7
Reed Creek Total				**21.3**	**37.2**	**-74.7**
Roanoke River	VA0083097	Old Dominion Electric Cooperative-Clover	001	197.4	336.1	-70.3
Roanoke River	VA0022241	Brookneal Town - Staunton River Lagoon	001	8.2	15.1	-83.3
Roanoke River	VA0001538	Dan River, Inc- Brookneal	001	474.8	256.9	45.9
Roanoke River	VA0020451	Town of Altavista-STP	001	21,311.1	697.5	96.7
Roanoke River	VA0001678	ITG Burlington Ind. LLC Hurt Plant	001	56,270.5	662.6	98.8
Roanoke River Total[b]				**78,262.0**	**1,968.3**	**97.5**
Lower Total				***78,283.3***	***2,005.5***	***97.4***

a. 2008 303(d) segment L12L-01-PCB
b. 2008 303(d) segment L19R-01-PCB

Table 6-5. Permitted stormwater dischargers tPCBs WLAs[a]

Stream	NPDES ID[b]	Stormwater discharger	Baseline (mg/yr)	WLA (mg/yr)	% Reduction
Upper Roanoke River					
North Fork Roanoke River	VAR050204	Wolverine Advanced Materials	12.70	0.13	99.000
North Fork Roanoke	VAR050251	Federal Mogul Corp - Blacksburg	30.12	0.30	99.000

Stream	NPDES ID[b]	Stormwater discharger	Baseline (mg/yr)	WLA (mg/yr)	% Reduction
River					
North Fork Roanoke River	VAR050340	Wolverine Advanced Materials - Blacksburg	7.78	0.08	99.000
North Fork Roanoke River	VAR051352	MRSWA Solid Waste Transfer Station MRF	54.91	0.55	99.000
North Fork Roanoke River Total			**105.50**	**1.06**	**99.000**
Masons Creek	VAR050174	Carbone of America Corporation	4.09	0.04	99.000
Masons Creek	VAR050762	Novozymes Biologicals, Inc.	1.76	0.02	99.000
Masons Creek Total			**5.85**	**0.06**	**99.000**
Peters Creek		Steel Dynamics	1.44	0.01	99.000
Peters Creek Total[c]			**1.44**	**0.01**	**99.000**
Tinker Creek		Advanced Metal Finishing	0.42	0.00	99.000
Tinker Creek		NSW	3.75	0.04	99.000
Tinker Creek		Packaging Corp. of America	3.11	0.03	99.000
Tinker Creek		The Roanoke Times	1.15	0.01	99.000
Tinker Creek	VAR050027	Auto Salvage and Sales Incorporated	0.78	0.01	99.000
Tinker Creek	VAR050275	Old Dominion Auto Salvage	3.12	0.03	99.000
Tinker Creek	VAR050436	Norfolk Southern Corp - Roadway Material Yard	0.68	0.01	99.000
Tinker Creek	VAR050520	O'Neal Steel Inc	16.12	0.16	99.000
Tinker Creek	VAR050530	Shenandoah Auto Parts	0.88	0.01	99.000
Tinker Creek	VAR050747	Parts Unlimited	3.43	0.03	99.000
Tinker Creek	VAR051262	Shorewood Packaging Corporation - Roanoke	2.18	0.02	99.000
Tinker Creek	VAR051315	A D Weddle Company Inc	4.04	0.04	99.000
Tinker Creek	VAR051460	Dynax America Corp USA	6.74	0.07	99.000
Tinker Creek	VAR051478	Precision Steel	2.07	0.02	99.000
Tinker Creek	VAR051492	Virginia Transformer Corp	4.49	0.04	99.000
Tinker Creek	VAR051570	Altec Industries Inc	13.60	0.14	99.000
Tinker Creek	VAR520005	Vishay Vitramon Inc	15.19	0.15	99.000
Tinker Creek Total[c]			**81.74**	**0.82**	**99.000**
Roanoke River		Accellent Cardiology, Inc.-Main Bldg	4.52	0.05	99.000
Roanoke River		Accellent Cardiology, Inc.-West Bldg	3.31	0.03	99.000
Roanoke River		Allied Tool & Machine Co., of Virginia	0.61	0.01	99.000
Roanoke River		Fabricated Metals Ind., Inc.	2.89	0.03	99.000
Roanoke River		Packaging Corp. of America	1,415.49	0.20	99.986
Roanoke River		Patterson Avenue CDD Landfill - Norfolk Southern Railway	14.44	0.14	99.000
Roanoke River		Roanoke Regional Landfill	0.53	0.01	99.000
Roanoke River		Sanitary Landfill at Mowles Spring Park (closed)	10.70	0.11	99.000
Roanoke River		Steel Dynamics	6.84	0.07	99.000
Roanoke River		Tecton Products, Roanoke VA	15.06	0.15	99.000
Roanoke River		Wise Recycling, LLC	0.86	0.01	99.000
Roanoke River	VAR050135	Virginia Scrap Iron & Metal Company Inc	4,896.27	0.24	99.995
Roanoke River	VAR050150	Graham White Manufacturing Company	19.75	0.20	99.000
Roanoke River	VAR050176	John W Hancock Jr LLC dba New Millennium Bldg Syst	1.75	0.02	99.000
Roanoke River	VAR050208	Walker Machine and Foundry Corp	6.82	0.07	99.000
Roanoke River	VAR050273	Ralph Smith Inc	2.77	0.03	99.000
Roanoke River	VAR050515	Yokohama Tire Corp	50.20	0.50	99.000
Roanoke River	VAR050522	Progress Rail Services Corp - Roanoke	6.08	0.06	99.000

Stream	NPDES ID[b]	Stormwater discharger	Baseline (mg/yr)	WLA (mg/yr)	% Reduction
Roanoke River	VAR050526	RR Donnelley and Sons Company - Roanoke	94.87	0.95	99.000
Roanoke River	VAR050717	Cycle Systems Incorporated	3.97	0.04	99.000
Roanoke River	VAR050741	Medeco Security Locks Inc	17.64	0.18	99.000
Roanoke River	VAR050775	Star City Auto Parts Inc	0.49	0.00	99.000
Roanoke River	VAR520200	Hancock Rack Syst dba New Millenium Building Syst	3.14	0.03	99.000
Roanoke River Total[c]			**6,578.99**	**3.11**	**99.953**
Upper Total			***6,773.52***	***5.05***	***99.925***
Lower Roanoke (Staunton) River					
Sycamore Creek		Burlington Industries - Hurt	92,387.54	1.47	99.998
Sycamore Creek Total			**92,387.54**	**1.47**	**99.998**
Lynch Creek		Graham Packaging Plastic Products	8.22	0.06	99.290
Lynch Creek Total			**8.22**	**0.06**	**99.290**
X-trib		BGF Industries	208,892.36	0.12	100.000
X-trib Total			**208,892.36**	**0.12**	**100.000**
Unnamed Trib to Roanoke River		Schrader Bridgeport	3,885.88	0.06	99.998
Unnamed Trib to Roanoke River Total			**3,885.88**	**0.06**	99.998
Black Walnut Creek		Dominion - Clover	112.13	0.80	99.290
Black Walnut Creek Total			**112.13**	**0.80**	99.290
Roanoke River		Abbott Labs	15.37	0.11	99.290
Roanoke River		BGF Industries	81,933.90	0.05	100.000
Roanoke River		Dominion - Altavista	7.66	0.05	99.290
Roanoke River		Dominion - Clover	725.61	5.15	99.290
Roanoke River		Dominion - Pittsylvania	0.00	0.00	0.000
Roanoke River		Schrader Bridgeport	38.47	0.00	99.999
Roanoke River Total[d]			**82,721.02**	**5.37**	**99.994**
Lower Total			**388,007.16**	**7.87**	***99.998***

a. Stormwater loads were assigned to streams based on the spatial orientation of the permitted area within the subbasin network
b. General stormwater permit NPDES IDs were not available for no-exposure sites and other select facilities
c. 2008 303(d) segment L12L-01-PCB
d. 2008 303(d) segment L19R-01-PCB

Table 6-6. MS4 tPCBs WLAs

Stream	MS4	Baseline (mg/yr)	WLA (mg/yr)	% Reduction
Upper Roanoke River				
North Fork Roanoke River	Blacksburg	823.7	8.2	99.000
North Fork Roanoke River	Christiansburg	166.8	1.7	99.000
North Fork Roanoke River Total		**990.5**	**9.9**	**99.000**
South Fork Roanoke River	Christiansburg	177.4	1.8	99.000
South Fork Roanoke River Total		**177.4**	**1.8**	**99.000**
Masons Creek	City of Salem	923.7	9.2	99.000
Masons Creek	Roanoke City	14.6	0.1	99.000
Masons Creek	Roanoke County	12.4	0.1	99.000
Masons Creek Total		**950.6**	**9.5**	**99.000**
Peters Creek	City of Salem	18.6	0.2	99.000
Peters Creek	Roanoke City	1,033.7	10.3	99.004
Peters Creek	Roanoke County	490.0	4.9	99.000

Stream	MS4	Baseline (mg/yr)	WLA (mg/yr)	% Reduction
Peters Creek Total[a]		**1,542.2**	**15.4**	**99.003**
Tinker Creek	Botetourt County	1,672.7	16.7	99.000
Tinker Creek	Roanoke City	5,135.2	51.4	99.000
Tinker Creek	Roanoke County	4,045.4	40.5	99.000
Tinker Creek Total[a]		**10,853.2**	**108.5**	**99.000**
Wolf Creek	Roanoke City	0.5	0.0	99.000
Wolf Creek	Roanoke County	1,053.2	10.5	99.000
Wolf Creek Total		**1,053.7**	**10.5**	**99.000**
Unnamed Trib to Roanoke River	Roanoke County	52.8	0.5	99.000
Unnamed Trib to Roanoke River Total		**52.8**	**0.5**	**99.000**
Roanoke River	City of Salem	4,451.6	44.5	99.000
Roanoke River	Roanoke City	84,565.4	99.6	99.882
Roanoke River	Roanoke County	5,038.7	50.4	99.000
Roanoke River Total[a]		**94,055.7**	**194.5**	**99.793**
Upper Total		***109,676.3***	***350.7***	***99.680***
Lower Roanoke (Staunton) River				
Goose Creek	Botetourt County	11.7	0.1	99.290
Goose Creek Total		**11.7**	**0.1**	**99.290**
Lower Total		***11.7***	***0.1***	***99.290***

a. 2008 303(d) segment L12L-01-PCB

6.2. Load Allocations

Generally, the LA is the amount of a pollutant contributed to the waterbody by nonpoint sources. For the purposes of this TMDL, nonpoint sources have been grouped into current and legacy sources. Current nonpoint sources include contributions of PCBs to the Roanoke River watershed from runoff of contaminated sites not within the spatial extent of MS4s or areas permitted for stormwater discharges. Contaminated sites have been categorized as known contaminated sites and urban background including unidentified contaminated sites. Legacy nonpoint sources include atmospheric deposition to surface waters and historically contaminated streambed sediment in the river.

Loadings from contaminated streambed sediments have been excluded from the TMDLs. The rationale for this exclusion is due to the dynamic relationship between the sediment and water column tPCB processes where the flux from sediments is a function of tPCBs concentrations in the stream water-sediment system as a whole (see Appendix G). Rather than a direct loading, the flux of tPCBs to-and-from streambed sediments can be characterized as an internal model mechanism. For this reason the loadings are not comparable to the direct loads contributed by the other sources. Table D-7 in Appendix D presents the initial streambed sediment concentration reductions applied to meet the TMDL condition in the upper and lower Roanoke (Staunton) subwatersheds.

LAs for nonpoint source categories in Roanoke River watershed streams grouped by watershed section are presented in Table 6-7. LAs for individual known contaminated sites not covered by MS4 or stormwater permits are presented in Table 6-8. Note that the loads calculated for all LA sources are estimates. Loads assigned to contaminated sites are based on estimates of upland soil PCB concentrations, while loads attributed to atmospheric deposition are based on literature sources (see Appendix G). In both cases additional PCB monitoring will have to be performed.

Table 6-7. Average annual tPCBs LAs for Roanoke River watershed streams

Stream	Known contaminated sites			Urban background and unidentified contaminated sites			Atmospheric deposition		
	Baseline (mg/yr)	LA (mg/yr)	% Reduction	Baseline (mg/yr)	LA (mg/yr)	% Reduction	Baseline (mg/yr)	LA (mg/yr)	% Reduction
Upper Roanoke River									
North Fork Roanoke River	0.0	0.0	0.0	3,184.8	31.8	99.0	631.6	631.6	0.0
South Fork Roanoke River	0.0	0.0	0.0	2,481.1	24.8	99.0	805.3	805.3	0.0
Masons Creek	0.0	0.0	0.0	623.9	6.2	99.0	197.1	197.1	0.0
Peters Creek[a]	0.0	0.0	0.0	76.1	0.8	99.0	32.1	32.1	0.0
Tinker Creek[a]	0.0	0.0	0.0	2,085.6	20.9	99.0	3,573.0	3,573.0	0.0
Wolf Creek	0.0	0.0	0.0	3.4	0.0	99.0	21.3	21.3	0.0
Unnamed Trib to Roanoke River	0.0	0.0	0.0	5.2	0.1	99.0	1.3	1.3	0.0
Roanoke River[a]	7,853.5	1.1	100.0	3,622.4	35.8	99.0	3,600.7	3,600.7	0.0
Upper Total	**7,853.5**	**1.1**	**100.0**	**12,082.4**	**120.4**	**99.0**	**8,862.5**	**8,862.5**	**0.0**
Lower Roanoke (Staunton) River									
Goose Creek	0.0	0.0	0.0	3,506.3	24.9	99.3	1,882.9	1,882.9	0.0
Sycamore Creek	0.0	0.0	0.0	647.3	4.6	99.3	191.5	191.5	0.0
Lynch Creek	7,034.0	0.1	100.0	612.8	3.1	99.5	15.5	15.5	0.0
Reed Creek	0.0	0.0	0.0	174.7	1.2	99.3	78.7	78.7	0.0
X-trib	6,065.5	0.1	100.0	168.4	0.5	99.7	0.9	0.9	0.0
Unnamed Trib to Roanoke River	8,349.1	0.1	100.0	595.8	2.2	99.6	17.8	17.8	0.0
Little Otter River[b]	0.0	0.0	0.0	3,330.4	23.6	99.3	603.9	603.9	0.0
Big Otter River	0.0	0.0	0.0	5,074.5	36.0	99.3	2,556.4	2,556.4	0.0
Straightstone Creek	0.0	0.0	0.0	172.3	1.2	99.3	292.5	292.5	0.0
Seneca Creek	0.0	0.0	0.0	272.9	1.9	99.3	420.0	420.0	0.0
Whipping Creek	0.0	0.0	0.0	234.1	1.7	99.3	164.3	164.3	0.0
Falling River	0.0	0.0	0.0	2,313.2	16.4	99.3	1,822.0	1,822.0	0.0
Childrey Creek	0.0	0.0	0.0	179.5	1.3	99.3	210.6	210.6	0.0
Catawba Creek	0.0	0.0	0.0	69.5	0.5	99.3	99.3	99.3	0.0
Turnip Creek	0.0	0.0	0.0	90.0	0.6	99.3	286.3	286.3	0.0
Hunting Creek	0.0	0.0	0.0	18.1	0.1	99.3	68.5	68.5	0.0
Cub Creek[c]	0.0	0.0	0.0	329.2	2.3	99.3	1,047.5	1,047.5	0.0
Black Walnut Creek	0.0	0.0	0.0	21.0	0.1	99.3	48.8	48.8	0.0
Roanoke Creek	0.0	0.0	0.0	948.8	6.7	99.3	1,498.1	1,498.1	0.0
Difficult Creek	0.0	0.0	0.0	339.2	2.4	99.3	484.0	484.0	0.0
Roanoke River[c]	62,453.1	0.9	100.0	3,151.9	14.4	99.5	12,576.0	12,576.0	0.0
Lower Total	**83,901.8**	**1.3**	**100.0**	**22,249.9**	**146.0**	**99.3**	**24,365.4**	**24,365.4**	**0.0**

a. 2008 303(d) segment L12L-01-PCB
b. 2008 303(d) segment L26R-01-PCB
c. 2008 303(d) segment L19R-01-PCB

Table 6-8. Known contaminated site tPCBs LAs

Stream	Contaminated site	Baseline (mg/yr)	LA (mg/yr)	% Reduction
Upper Roanoke River				
Roanoke River	Dixie Caverns	7,853.517	1.101	99.986
Roanoke River Total[b]		**7,853.517**	**1.101**	**99.986**
Upper Total		***7,853.517***	***1.101***	***99.986***

Stream	Contaminated site	Baseline (mg/yr)	LA (mg/yr)	% Reduction
Lower Roanoke (Staunton) River				
Lynch Creek	Lane Furniture Co.	1,654.530	0.025	99.998
Lynch Creek	Oil distributors-Altavista	1,846.731	0.029	99.998
Lynch Creek	West town Dump-Altavista	3,532.784	0.053	99.998
Lynch Creek Total		**7,034.044**	**0.107**	**99.998**
X-trib	Altavista STP	3,977.088	0.060	99.998
X-trib	East town Dump-Altavista	1,991.809	0.030	99.998
X-trib	Lane Furniture Co.	96.643	0.001	99.998
X-trib Total		**6,065.540**	**0.091**	**99.998**
Unnamed Trib to Roanoke River	A. O. Smith	3,760.673	0.058	99.998
Unnamed Trib to Roanoke River	Schrader Bridgeport[a]	4,588.422	0.069	99.998
Unnamed Trib to Roanoke River Total		**8,349.095**	**0.126**	**99.998**
Roanoke River	Altavista STP	8,750.517	0.132	99.998
Roanoke River	Dan River Inc.	28,703.655	0.433	99.998
Roanoke River	East town Dump-Altavista	3,256.645	0.049	99.998
Roanoke River	English Construction	3,930.367	0.061	99.998
Roanoke River	Lane Furniture Co.	10,990.042	0.166	99.998
Roanoke River	Schrader Bridgeport	186.755	0.003	99.998
Roanoke River	West town Dump-Altavista	6,635.100	0.101	99.998
Roanoke River Total[c]		**62,453.079**	**0.944**	**99.998**
Lower Total		***83,901.758***	***1.269***	***99.998***

a. Schrader Bridgeport is characterized as a contaminated site and stormwater site because the contaminated area extends beyond the area permitted for stormwater discharges
b. 2008 303(d) segment L12L-01-PCB
c. 2008 303(d) segment L19R-01-PCB

6.3. Margin of Safety

The MOS is the portion of the pollutant loading reserved to account for any uncertainty in the data. There are two ways to incorporate the MOS: (1) implicitly incorporate the MOS by using conservative model assumptions to develop allocations or (2) explicitly specify a portion of the TMDL as the MOS and use the remainder for allocations. A 5 percent explicit MOS was applied to account for uncertainty in this TMDL. LAs and WLAs were reduced by 5 percent to offset the loading attributed to MOS. In addition, other implicit MOS factors were inherently included in the modeling analysis because of the requirements of the models and input data properties, including not simulating the decay of PCBs.

6.4. Critical Conditions and Seasonal Variation

TMDLs must be developed with consideration of critical conditions and seasonal variation. The critical condition is the set of environmental conditions, which, if met, will ensure the attainment of objectives for all other conditions. The critical conditions for PCB loading to the Roanoke River watershed include both storm magnitude precipitation, which causes uplands soil erosion and streambed scour, and low-flow conditions, which cause water quality target exceedances at locations where highly contaminated sediments have accumulated. The LSPC model simulates precipitation variability throughout the watershed as represented by the weather time-series used to drive the model. Thus, the model inherently covers the range of hydrologic conditions that occur in the watershed, including storm-flow and low-flow conditions. Seasonal variation is also captured in the time variable simulation, which represents seasonal precipitation on a year-to-year basis.

7. REASONABLE ASSURANCE

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels from both point sources and nonpoint sources. The following sections outline the framework used in Virginia to provide reasonable assurance that the required pollutant reductions can be achieved. While neither the Clean Water Act nor current EPA regulations direct states to develop a detailed implementation plan as part of the TMDL development and approval process, reasonable assurance for implementing the allocated loadings is required as part of the TMDL process. The TMDL IP is a requirement of Virginia's 1997 Water Quality Monitoring, Information, and Restoration Act or WQMIRA (§62.1-44.19:4 through 19:8 of the Code of Virginia). Adaptive Implementation, TMDL WLA implementation through VPDES permitting and conventional Implementation Plan development are all strategies discussed in this chapter to achieve reasonable assurance.

7.1. Adaptive Implementation Strategy

VADEQ intends to implement this TMDL using an adaptive implementation strategy. As described by Wong (2006), adaptive implementation is an iterative implementation process that makes progress toward achieving water quality goals while using new data and information to reduce uncertainty and adjust implementation activities. The focus of this approach is oriented towards increasingly efficient management and restoration and is not generally anticipated to lead to a re-opening of the TMDL. However, the TMDL and allocation scenarios can be changed if warranted by new data and information.

Adaptive implementation will be particularly useful for the Roanoke River PCB TMDL because of the complexities and uncertainties involved in understanding the fate and transport of PCBs. New data and information will be used to direct control strategies aimed to mitigate PCB loadings to the watershed. Additional information will also help to better understand and characterize PCB loadings from key sources, many of which are still unknown or unconfirmed in the upper Roanoke River watershed. Ultimately, this strategy allows responsiveness to new information while providing the flexibility in implementing the TMDL.

7.2. Implementation of Waste Load Allocations

To implement the WLA component of the TMDL, Virginia utilizes the National Pollutant Discharge Elimination System (NPDES) program administered by the Commonwealth (known as Virginia Pollution Discharge Elimination System, or VPDES) under the authority delegated by EPA. Federal regulations require that all new or revised NPDES permits be consistent with the assumptions and requirements of any applicable TMDL WLA (40 CFR §122.44 (d)(1)(vii)(B)). These regulations allow permits to use best management practices (BMPs) in lieu of numeric effluent limitations under certain conditions (40 CFR 122.44(k)). The regulation, in subsections 3 and 4, states that BMP-based water quality based effluent limits (WQBELs) can be used where "Numeric effluent limitations are infeasible; or [t]he practices are reasonably necessary to achieve effluent limitations and standards or to carry out the purposes and intent of the CWA."

In circumstances where final effluent PCB data do not exist or additional characterization is necessary to determine attainment of the WLA, special conditions shall be incorporated into VPDES permits (including municipalities, industrial wastewater, industrial stormwater under individual or general permits) either during modification or re-issuance. To ensure the PCB monitoring requirements are consistently applied, VADEQ has developed PCB point source monitoring guidance (VADEQ, 2009). The document provides guidelines on selecting applicable facilities, final effluent sample collection, PCB analysis using a low-level PCB method (EPA Method 1668) and data reporting requirements. This requirement shall also apply to MS4 systems as WLAs have been included in the TMDL.

As mentioned previously, non-numeric WQBELs (BMPs) will be used to comply with the WLA provisions of the Roanoke River PCB TMDL. Where warranted, non numeric BMPs shall be implemented and will focus on PCB source tracking and elimination at the site of contamination, rather than end-of-pipe controls. These BMPs, also referred to as Pollutant Minimization Plans (PMP) would be submitted by the permittee for review and approval. The permittee would be required to execute and periodically update the plan until monitoring and/or compliance with approved BMPs demonstrate that the assigned WLA is consistently met. Essential components of a PMP are as follows:

- Dischargers provide a framework for tracking sources of PCBs within their system. An important component includes the review of historical activities on properties under their control for past presence or known spills of PCBs.
- PMPs must contain specific actions, timetables, and assessment of the effectiveness of the actions. An example of action(s) can include steps needed to locate and control unknown PCB sources.
- Measurement and demonstration of progress in reducing PCBs.

7.3. Implementation of Load Allocations

LAs are assigned to nonpoint sources, including known contaminated sites, urban background and unidentified contaminated sites, and atmospheric contamination. Contaminated streambed sediments can also be considered within this category but are not expressed within this TMDL as a direct (or external) source. Under the adaptive implementation approach, the Commonwealth intends to use existing programs in order to attain water quality goals. Available programmatic options include a combination of regulatory authorities, such as the NPDES (WLA component) and Toxics Substances Control Act (TSCA), as well as state programs including the Voluntary Remediation Program (VRP), *Toxics Contamination Source Assessment Policy*, and the Virginia Environmental Emergency Response Fund (VEERF). The *PCB Strategy for the Commonwealth of Virginia*, published in October 2004, establishes the general strategy and outlines the regulatory framework and state initiatives that Virginia will use to address PCB impaired waterbodies. This document is available at: www.deq.virginia.gov/fishtissue/pcbstrategy.html.

Atmospheric deposition sources of PCBs can be numerous and difficult to quantify. PCBs enter the air through a variety of pathways, and the deposition of PCBs from the atmosphere to the land surface and the volatilization of PCBs from the land to the atmosphere are not well understood. Atmospheric deposition studies will help identify these pathways, and efforts to remediate contaminated sites will help reduce possible atmospheric contributions.

tPCBs in streambed sediments are contributing to the system through the dynamic relationship between the sediment and waster processes. This occurs through sediment resuspension and/or partitioning from sediment through desorption. PCB desorption was especially evident during low river flows where water quality target violations occurred within the water column. To address contaminated bed sediments where hot spots exist, mechanical or vacuum dredging could be explored as an option to permanently remove PCBs from the system.

7.3.1. Implementation Plan Development

For the implementation of the TMDL's LA component, a TMDL implementation plan will be developed that addresses at a minimum the requirements specified in the Code of Virginia, Section 62.1-44.19.7. Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters". The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards (US EPA 1999).

In order to qualify for other funding sources, such as EPA's Section 319 grants, additional plan requirements may need to be met. The detailed process for developing an implementation plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the VADEQ and Virginia Department of Conservation and Recreation (VADCR) TMDL project staff or at http://www.deq.virginia.gov/tmdl/implans/ipguide.pdf

Watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL implementation plan. Regional and local offices of VADEQ, VADCR, the Virginia Department of Game and Inland Fisheries and other cooperating agencies are technical resources to assist in this endeavor. With successful completion of implementation plans, local stakeholders will have a blueprint to restore impaired waters and enhance the value of their land and water resources. Additionally, development of an approved implementation plan may enhance opportunities for obtaining financial and technical assistance during implementation.

7.4. Follow-up monitoring

Following the development of the TMDL, VADEQ will make every effort to continue to monitor the PCB impaired waterbodies in accordance with the fish tissue, sediment, and special study monitoring programs. The objectives are twofold: 1) to assess progress made toward achieving the Roanoke River PCB TMDL, and 2) with the Statewide Fish Tissue and Sediment Monitoring Program to systematically assess and evaluate, using a multi-tier screening, waterbodies in Virginia in order to identify toxic contaminant(s) accumulation that may adversely affect human users of the resource. It is also suggested that monitoring of water column and streambed sediment PCB concentrations be continued through special studies.

The purpose, location, parameters, frequency, and duration of the monitoring will be determined by the VADEQ staff, in cooperation with stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be in similar locations as the listing stations. At a minimum, the monitoring stations should be representative of the original impaired segments. The details of the follow-up monitoring will be outlined in the annual Fish Tissue and Sediment Monitoring Plan prepared by VADEQ's Water and Biological Monitoring Program. Other agency personnel, watershed stakeholders, etc. may provide input on the annual water monitoring plan.

The long term monitoring of fish tissue, sediment and, as resources allow, ambient water concentrations for PCBs will be used to evaluate trends in PCB concentrations in different environmental media, better characterize PCB loadings into the watershed and identify potential PCB hotspots for remedial activity. New information will be considered in light of the TMDL reduction goals. Recommendations may then be made, when necessary, to target implementation efforts in specific areas and continue or discontinue monitoring at follow-up stations.

7.4.1. On-going efforts to characterize and reduce PCB loadings

In 2006, the General Assembly passed legislation requiring the Secretary of Natural Resources to develop a plan for the cleanup of the Chesapeake Bay and Virginia's waters (HB 1150). This plan was completed in 2007 (Commonwealth of Virginia 2007). The plan addresses both point and non-point sources of pollution and includes measurable and attainable objectives for water cleanup, attainable strategies, a specified timeline, funding sources, and mitigation strategies. Additionally, challenges to meeting the clean up plan goals (i.e. lack of program funding, staffing needs, monitoring needs) are identified. Information regarding Virginia's Water Clean-Up Plan can be found at http://www.naturalresources.virginia.gov/Initiatives/WaterCleanupPlan/.

Reductions in sediment from construction sites and development areas will also be of benefit for reducing PCBs. The Virginia Erosion and Sediment Control and Virginia Stormwater Management Programs—administered by the Department of Conservation and Recreation and delegated to local jurisdictions—provide the framework for implementing sediment reduction BMPs throughout localities. More information regarding these programs can be found at http://www.dcr.virginia.gov/soil_&_water/e&s.shtml.

8. PUBLIC PARTICIPATION

It is the policy of the Commonwealth of Virginia and EPA to require public participation as part of the TMDL development process. The public comment period for this TMDL begins on July 29, 2009 and ends August 27, 2009. A public notice was published in the *Virginia Register* on July 20, 2009. Two separate public meetings will be held for presentation and discussion of the PCB TMDL development. The upper Roanoke River meeting is scheduled for Wednesday, July 29, at 7 p.m. at the DEQ Blue Ridge Regional Office conference room located at 3019 Peters Creek Road in Roanoke. The lower Roanoke (Staunton) River meeting is scheduled for Thursday, July 30, at 7 p.m. at the Brookneal Elementary School gymnasium located at 1330 Charlotte St. in Brookneal.

During the public comment period, VADEQ welcomes input from interested parties and the general public on the proposed TMDL document. **All comments must be postmarked no later than the close of the comment period, July 27, 2009.** Send comments to either Ms. Mary R. Dail or Ms. Amanda B. Gray.

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Appendix A: Development of BAFs and Water Quality Targets for the Roanoke River PCB TMDL Study

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A1. INTRODUCTION

This document describes how species bioaccumulation factors (BAF) are computed from observed PCB concentrations in fish tissue samples and nearby water column samples. Results are presented for both individual species and trophic levels (planktivore, benthivore-generalist, and predator), similar to the approach used in the Potomac PCB draft TMDL report (ICPRB 2007) which used the guidelines outlined in the USEPA 2003 technical support document for development of bioaccumulation factors. Water column targets for allowable PCB concentrations can be derived by dividing the state's fish tissue criterion or screening threshold by some factor that represents the fish's ability to absorb and retain PCBs.

The revised EPA guidelines (USEPA 2003) recommend using BAF instead of bio-concentration factors (as was done in the 1980 EPA guidelines) for persistent, hydrophobic chemicals such as PCBs. The "total" BAF is also the ratio of the PCB concentration in an organism's wet tissue to its concentration in water. However, it is measured in situations where both the organism and its food and environment are exposed to PCBs.

Baseline BAFs (total BAFs normalized to freely dissolved PCBs in the water and lipid content of the fish tissue), were calculated to identify those species most susceptible to accumulating and maintaining PCBs. These normalized BAFs were used to derive total BAFs adjusted to a common condition for comparison purposes. Finally, these computed BAFs were used to establish water quality targets for the Roanoke model that achieve allowable PCB concentrations in the consumable tissue of fish.

A2. TOTAL BAFS

Calculation of a BAF requires information on total concentration of PCB in the fish and total concentration of PCB in the ambient water. Total PCB water column data were available only from the recent whole water analysis (n = 10 samples) conducted during the TMDL special study in 2007–2008 (August to May). Adjusted total PCB data were used for the analysis (Richards 2007). All historical total PCB data in the water column were at detection limits and, therefore, could not be used. Fish tissue data corresponding to these ten water quality sampling stations were available for a similar time period (2006).

The fish tissue data included 16 different fish species. Only five of the 16 species had a sample size of greater than 10, with Carp having the most samples (n=104), the other species being Striped Bass (n=62), Cannel Catfish (n=52), Redhorse Sucker (n=24), and Redbreast Sunfish (n=14). Each fish tissue sampling station was associated with a corresponding water column and assigned a corresponding whole water total PCB concentration. The paired fish tissue-water column data was then split into two groups, those located above Niagra Dam (upper) and those located below Leesville Dam (lower). This was done because of three major dams separating the two areas (Niagra Dam, Smith Mtn. Dam, and Leesville Dam) and the available water column monitoring data suggests that levels and types of PCB contamination differ between the two sections (upper and lower) (Tetra Tech 2009). Table 2-1 shows the water column station and associated fish tissue station. Figure 2-1 shows the stations located spatially along the Roanoke River.

Table A2-1. Water column station and associated fish tissue station used in BAF analysis

Water Column Station ID	Associated Fish Tissue Station
4ACUB002.21	4ACUB010.96
4AROA059.12	4AROA059.12
4AROA067.91	4AROA067.91
4AROA097.76	4AROA097.07
4AROA127.79	4AROA129.95
4AROA129.55	4AROA129.95
4AROA131.55	4AROA129.95
4AROA199.20	4AROA199.20
4AROA204.76	4AROA206.80
4AROA207.08	4AROA206.80

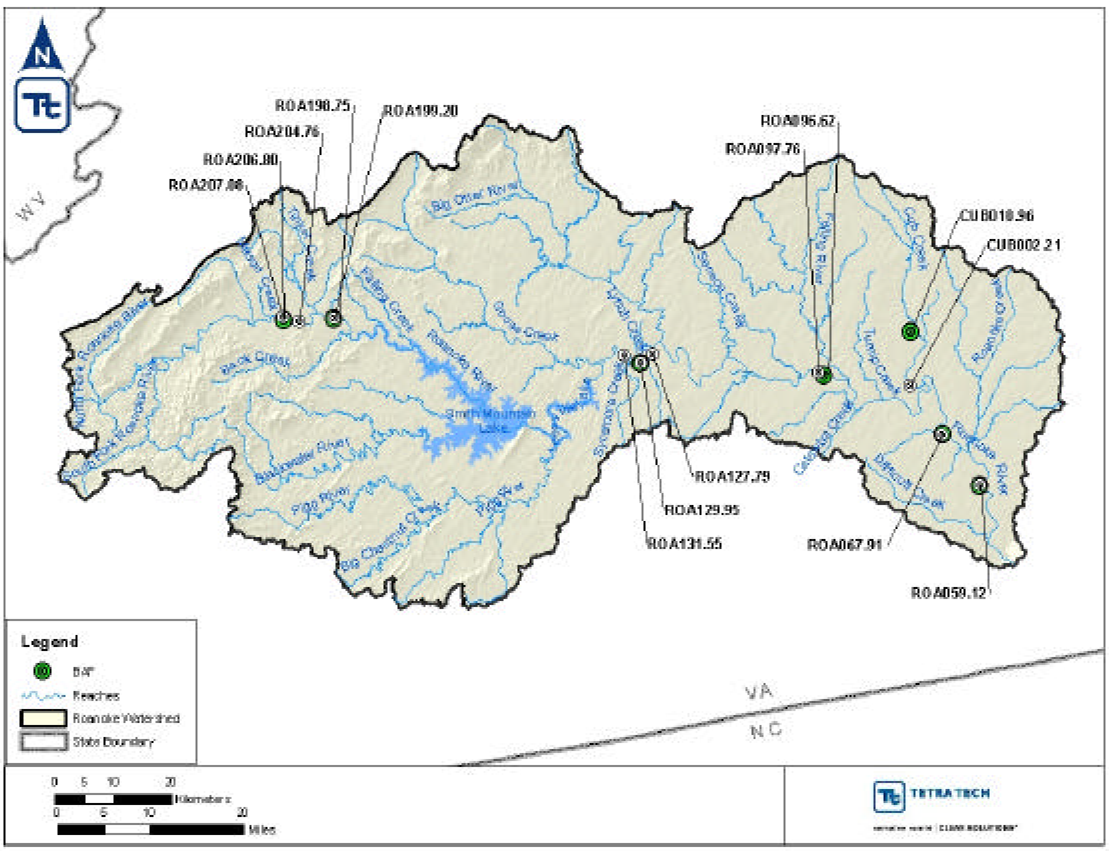

Figure A2-1 BAF monitoring station locations in the Roanoke River watershed.

Total BAFs or field measured BAFs were calculated using the equation given below (EPA 2000, 2003):

$$totalBAF = \frac{[tPCB]_{tissue}}{[tPCB]_{water}} \qquad \text{[Eq 1.]}$$

where $[tPCB]_{tissue}$ = concentration of tPCB in wet fish tissue (μg/kg)

$[tPCB]_{water}$ = concentration of tPCB in water (µg/liter)

Species-specific total BAFs derived from the observed Roanoke River fish and water column total PCB concentrations are highly variable, with BAF values for a species ranging as much as three orders of magnitude. This variability within species is to be expected given day-to-day fluctuations in PCB loadings to the water column. Median total BAF values for the lower section of the watershed range from 26,226 L/kg (Redear Sunfish) to 1,354,560 L/kg (Smallmouth Bass). Median total BAF values for the upper section of the watershed range from 55,741 L/kg (White Sucker) to 231,159 L/kg (Carp). In general, the total BAFs were always higher than the default bio-concentration value (31,200) recommended in the 1980 EPA guidelines for 304(a) PCB criteria. Out of the species with greater than ten samples, the highest median total BAFs computed were for Carp and Smallmouth Bass in the upper and lower Roanoke, respectively.

Median total BAF values for each species grouped by watershed section as well as for the three trophic levels are shown in Tables 2-2 and 2-3 respectively. Trophic level BAFs were determined by pooling the species samples by trophic level and calculating the geometric means of all the samples, regardless of species (USEPA 2003).

Table A2-2. Median total BAF values by species

Section	Trophic Level	Fish species name	Count (n)	Total BAF (L/Kg)
Upper	Benthivore / Generalist	Carp	20	231,158.8
Upper	Benthivore / Generalist	Redhorse Sucker	2	132,670.4
Upper	Benthivore / Generalist	Golden Redhorse Sucker	4	123,093.4
Upper	Benthivore / Generalist	White Sucker	4	55,740.5
Lower	Predator	Smallmouth Bass	6	1,354,599.9
Lower	Predator	Rock Bass	6	571,527.5
Lower	Benthivore / Generalist	Carp	84	493,262.8
Lower	Predator	Striped Bass	62	373,096.7
Lower	Predator	Walleye	4	362,022.8
Lower	Benthivore / Generalist	Redbreast Sunfish	14	300,603.6
Lower	Benthivore / Generalist	Redhorse Sucker	22	243,858.3
Lower	Predator	Blue Catfish	4	201,165.0
Lower	Planktivore	Gizzard Shad	8	185,970.7
Lower	Benthivore / Generalist	Channel Catfish	52	181,403.6
Lower	Benthivore / Generalist	Golden Redhorse Sucker	2	160,037.6
Lower	Predator	White Bass	4	145,140.2
Lower	Benthivore / Generalist	Black Crappie	2	61,496.6
Lower	Predator	Largemouth Bass	2	56,886.4
Lower	Benthivore / Generalist	Redear Sunfish	2	26,226.1

Table A2-3. Trophic Level total BAF values (geometric mean)

Section	Trophic Level	Count (n)	Total BAF (L/Kg)
Upper	Benthivore / Generalist	30	166,163.6
Lower	Benthivore / Generalist	178	355,623.3
Lower	Predator	88	292,288.7
Lower	Planktivore	8	173,072.3

A3. BASELINE BAFS

Total BAFs for PCBs vary depending on the food habits and lipid concentrations of each fish species and on the concentration of freely-dissolved PCBs in the water column. EPA recommends calculating a "baseline" BAF for the purpose of extrapolating between different species and bodies of water (USEPA 2003). These BAFs are also useful in identifying the species most susceptible to accumulating and retaining PCBs. The baseline BAF is the total BAF normalized to the fish tissue lipid content and the freely-dissolved PCB concentration in the water (USEPA 2003, ICPRB 2007)

$$baselineBAF = \left[\frac{totalBAF}{F_d} - 1\right] \cdot \frac{1}{\%lipid} \qquad \text{[Eq 2.]}$$

where totalBAF = Total BAF of PCB calculated using Eq. 1.
F_d = fraction of total PCB in water that is freely dissolved
$\%lipid$ = fraction of tissue that is lipid

The freely-dissolved PCB concentration is a function of dissolved and particulate organic carbon concentrations in the water column. However, this analysis was simplified to a suspended solids basis due to the lack of readily available dissolved and particulate carbon (DOC and POC) data. The dissolved fraction (F_d) of total PCB in water was calculated using [Eq.3 or Eq.4] given below:

$$F_d = \frac{1}{1 + m \cdot K_d} \qquad \text{[Eq 3.]}$$

where m = suspended solids concentration (mg/L)
K_d = partitioning coefficient for PCB

Suspended solids concentration from five stations were assigned to the matched fish tissue-water column PCB data and used to calculate baseline BAFs (2007–2008). Only data points where water column PCB and TSS concentrations were collected during the same sampling event were used. Table 3-1 shows the mean suspended solids concentration.

Table A3-1 Mean total suspended solids concentrations at analysis monitoring stations

Station ID	Count (n)	Mean TSS (mg/L)
4ACUB002.21	2	20.5
4AROA059.12	5	16.2
4AROA067.91	5	22.2
4AROA097.76	6	17.3
4AROA127.79	1	4.0
4AROA129.55	6	43.0
4AROA131.55	3	30.0
4AROA199.20	2	52.5
4AROA204.76	2	21.5
4AROA207.08	2	25.5

The partitioning coefficient for PCB can be approximated to the following equation given below from Thomann and Mueller (1987):

$$K_d = 1\times10^{-6} \cdot \mathrm{f_{oc}} \cdot \mathrm{K_{ow}}$$

where : f_{oc} = weight fraction of the total carbon in the solid matter (gC/g) and can be computed from the relationship $POC = \mathrm{f_{oc}} \cdot m$ and

K_{ow} = octanol-water PCB partition coefficient

Substituting this approximation into [Eq.3] we get:

$$F_d = \frac{1}{1 + (1\times10^{-6} \cdot \mathrm{K_{ow}}) \cdot \mathrm{f_{oc}} \cdot m} \quad \text{[Eq 4.]}$$

Partition coefficients of PCB (K_{ow}) congeners range over four orders of magnitude. A weighted homolog was calculated for each water column concentration data point and used to estimate the associated K_{ow} for the BAF calculation. Homolog specific partitioning coefficients for PCBs are presented below in Table 3-2.

Table A3-2 Homolog specific partitioning coefficients

Homolog	Middle log Kow
Kow_mono+di	4.675
Kow_tri	5.425
Kow_tetra	6.005
Kow_penta	6.525
Kow_hexa	6.73
Kow_hepta	7.235
Kow_octa	7.6
Kow_nona	7.915
Kow_deca	8.18

Source: ICPRB, 2007

The f_{oc} value was calculated using the following relationship $POC = \mathrm{f_{oc}} \cdot m$.

POC data were extrapolated from measured TOC values (TOC data collected in conjunction with the TSS data). POC was estimated from observed TOC data using the ratio of DOC to TOC that was estimated based on the TMDL special study dataset (WCRO data – from Richards M., 8/10/07). A ratio of POC/TOC = 0.10 was used to estimate the POC (calculated based on samples where DOC < TOC). Based on National default values of POC and DOC given in USEPA, 2003 the POC to TOC ratio is 0.17. This computed POC, along with the suspended solids concentration, was used to estimate the fraction of organic carbon f_{oc} for each station. Suspended solids values for each station were multiplied by 0.10 to estimate the POC at each station.

For individual fish samples, the total PCB concentration in the fish tissue was normalized to that sample's measured lipid fraction, and then divided by the concentration of freely-dissolved total

PCB as shown in [Eq. 2]. The highest median baseline BAFs (i.e. which most readily absorb and maintain total PCBs) were for Carp in both the upper and lower watershed sections (Table 3-4).

Table A3-4. Median baseline BAF values by species and watershed section

Section	Trophic Level	Fish species name	Count (n)	Total BAF (L/Kg)
Upper	Benthivore / Generalist	Carp	20	1,691,732.6
Upper	Benthivore / Generalist	Golden Redhorse Sucker	4	1,351,113.7
Upper	Benthivore / Generalist	Redhorse Sucker	2	1,222,709.4
Upper	Benthivore / Generalist	White Sucker	4	673,166.7
Lower	Predator	Smallmouth Bass	6	63,021,024.6
Lower	Predator	Rock Bass	6	22,802,020.7
Lower	Benthivore / Generalist	Redbreast Sunfish	14	16,990,173.2
Lower	Benthivore / Generalist	Carp	84	7,394,544.6
Lower	Predator	Walleye	4	5,424,439.8
Lower	Benthivore / Generalist	Redhorse Sucker	22	4,843,871.5
Lower	Benthivore / Generalist	Golden Redhorse Sucker	2	3,544,944.5
Lower	Predator	Largemouth Bass	2	3,120,453.4
Lower	Predator	Blue Catfish	4	3,007,903.7
Lower	Benthivore / Generalist	Channel Catfish	52	2,144,105.3
Lower	Predator	White Bass	4	1,924,718.3
Lower	Predator	Striped Bass	62	1,336,420.6
Lower	Benthivore / Generalist	Redear Sunfish	2	1,117,173.5
Lower	Planktivore	Gizzard Shad	8	889,057.3
Lower	Benthivore / Generalist	Black Crappie	2	774,068.5

A4. ADJUSTED TOTAL BAFS

A species' baseline BAF can be standardized to a common condition by normalizing based on the median lipid content of that species and a single freely-dissolved PCB concentration representative of the ecosystem (the median dissolved concentration across all stations grouped by watershed section was used in the analysis). This calculation results in adjusted total BAFs for each species with no variability attributable to differences in fish lipid content or freely-dissolved PCB concentrations in the water column:

$$AdjustedTotalBAF = [(baselineBAF \cdot median\%lipid) + 1] \cdot medianF_d \qquad \text{[Eq 5.]}$$

The adjusted total BAF [Eq.5] is the species' baseline BAFs adjusted to the species' median % lipid and the overall median % freely-dissolved total PCBs. Table 4-1 shows the adjusted total BAF values by species.

The VADEQ fish tissue screening threshold for total PCBs was then divided by the median adjusted total BAF to derive a water column total PCB target for the entire Roanoke River. The fish tissue PCB threshold in Virginia is currently 54 ng/g. The mean adjusted total BAF for each species and the associated water column PCB targets for each species are shown in Table 4-1.

Table A4-1. Adjusted total BAFs and associated VA water column total PCB targets

Model Section	Trophic Level	Fish species name	Median Adjusted Total BAF (L/kg)	Count (n)	WC Target (ng/L)
Upper	Benthivore / Generalist	Carp	139,520	20	0.387
Upper	Benthivore / Generalist	Golden Redhorse Sucker	124,929	4	0.432
Upper	Benthivore / Generalist	Redhorse Sucker	74,307	2	0.727
Upper	Benthivore / Generalist	White Sucker	56,572	4	0.955
Lower	Predator	Smallmouth Bass	1,546,278	6	0.035
Lower	Benthivore / Generalist	Carp	680,218	84	0.079
Lower	Predator	Rock Bass	652,399	6	0.083
Lower	Benthivore / Generalist	Redbreast Sunfish	504,013	14	0.107
Lower	Predator	Walleye	390,034	4	0.138
Lower	Predator	Striped Bass	385,038	62	0.140
Lower	Benthivore / Generalist	Golden Redhorse Sucker	365,606	2	0.148
Lower	Benthivore / Generalist	Redhorse Sucker	328,347	2	0.164
Lower	Planktivore	Gizzard Shad	315,748	2	0.171
Lower	Benthivore / Generalist	Channel Catfish	228,087	52	0.237
Lower	Predator	Blue Catfish	222,532	4	0.243
Lower	Predator	White Bass	165,524	4	0.326
Lower	Predator	Largemouth Bass	64,721	2	0.834
Lower	Benthivore / Generalist	Black Crappie	60,673	2	0.890
Lower	Benthivore / Generalist	Redear Sunfish	29,838	2	1.810

A higher adjusted total BAF will result in a lower target water concentration, which should be protective of all fish species with lower BAFs. Based on the BAF analysis (Table 4-1) several fish species have a water column target value of an order of magnitude lower than the current VA water column target for human health of 1.7 ng/L (i.e. more stringent then the current criteria). It is suggested that the target be based on the Carp BAF of 139,520 for the upper section and Striped Bass BAF of 385,038 for the lower section. Based on the VADEQ fish tissue threshold, these BAFs equate to water quality targets of 0.387 and 0.140 ng/L, for the upper and lower sections, respectively. Carp is suggested as the target species for the upper section of the Roanoke because it is the only species with an adequate sample size (n=20) and is protective of water quality. Striped Bass is suggested as the target species for the lower section of the Roanoke because of its robust sample size (n=62) and stakeholder concern about the protection of sporting fish species. Smallmouth and Rock Bass, two other sport species with lower water quality targets, had inadequate sample sizes (n=6).

A5. REFERENCES

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Appendix B:
Roanoke River PCB TMDL Water Quality Monitoring Summary

LIST OF TABLES

Table B-1. Fish tissue PCB monitoring data summary for the Roanoke River watershed

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	1	Black Crappie	32.0	32.0	32.0	1
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	1	Carp	699.0	699.0	699.0	1
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	1	Channel Catfish	318.1	318.1	318.1	1
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	4	Flathead Catfish	149.3	831.3	497.1	4
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	1	Largemouth Bass	132.8	132.8	132.8	1
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	5	Striped Bass	98.7	480.3	343.6	5
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	2	Walleye	67.6	150.8	109.2	2
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	3	White Bass	144.9	428.3	282.6	3
4AROA052.69	Roanoke River near Clover Landing	3/31/1999	3	White Perch	148.5	166.3	156.2	3
4AROA059.12	Roanoke River near Rt. 360 - Clover	10/27/1998	1	Bluegill Sunfish	51.5	51.5	51.5	1
4AROA059.12	Roanoke River near Rt. 360 - Clover	5/3/1993-4/17/2006	21	Carp	9.3	1711.8	626.1	21
4AROA059.12	Roanoke River near Rt. 360 - Clover	5/3/1993-4/17/2006	20	Channel Catfish	32.3	820.7	271.7	20
4AROA059.12	Roanoke River near Rt. 360 - Clover	4/17/2002	1	Gizzard Shad	224.5	224.5	224.5	1
4AROA059.12	Roanoke River near Rt. 360 - Clover	4/17/2002-4/17/2006	2	Largemouth Bass	84.4	119.3	101.8	2
4AROA059.12	Roanoke River near Rt. 360 - Clover	4/17/2002	1	Quillback Carpsucker	179.0	179.0	179.0	1
4AROA059.12	Roanoke River near Rt. 360 - Clover	4/17/2006	1	Redear Sunfish	38.9	38.9	38.9	1
4AROA059.12	Roanoke River near Rt. 360 - Clover	10/27/1998-4/17/2006	4	Redhorse Sucker	44.8	388.2	250.5	4

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4AROA059.12	Roanoke River near Rt. 360 - Clover	10/27/1998	3	Spotted Bass	89.8	152.9	113.7	3
4AROA059.12	Roanoke River near Rt. 360 - Clover	5/2/2002-4/17/2006	16	Striped Bass	308.3	898.9	602.0	16
4AROA059.12	Roanoke River near Rt. 360 - Clover	5/13/1993	9	Sunfish	8.8	75.4	39.3	9
4AROA059.12	Roanoke River near Rt. 360 - Clover	5/2/2002	1	Walleye	241.9	241.9	241.9	1
4AROA059.12	Roanoke River near Rt. 360 - Clover	5/3/1993-4/17/2006	12	White Bass	149.8	1209.2	484.8	12
4AROA059.12	Roanoke River near Rt. 360 - Clover	5/3/1993	9	White Perch	26.7	369.4	120.1	9
4AROC005.35	Roanoke Creek near Saxe	8/27/1999	1	Bluegill Sunfish	4.5	4.5	4.5	1
4AROC005.35	Roanoke Creek near Saxe	8/27/1999	1	Redbreast Sunfish				0
4AROA067.91	Roanoke River near Rt. 746	9/25/2006	2	Blue Catfish	189.1	345.3	267.2	2
4AROA067.91	Roanoke River near Rt. 746	8/5/1999	1	Bluegill Sunfish	28.0	28.0	28.0	1
4AROA067.91	Roanoke River near Rt. 746	8/5/1999-9/25/2006	9	Carp	275.2	1553.3	782.9	9
4AROA067.91	Roanoke River near Rt. 746	8/5/1999-9/25/2006	2	Channel Catfish	240.1	833.6	536.8	2
4AROA067.91	Roanoke River near Rt. 746	9/25/2006	1	Gizzard Shad	246.1	246.1	246.1	1
4AROA067.91	Roanoke River near Rt. 746	9/25/2006	1	Golden Redhorse Sucker	211.8	211.8	211.8	1
4AROA067.91	Roanoke River near Rt. 746	8/5/1999	1	Redhorse Sucker	171.2	171.2	171.2	1
4AROA067.91	Roanoke River near Rt. 746	8/5/1999	1	Spotted Bass	38.8	38.8	38.8	1
4AROA067.91	Roanoke River near Rt. 746	9/25/2006	2	Walleye	291.9	671.0	481.5	2
4AHTA003.26	Hunting Creek (Conner Lake)	6/21/2006	1	Channel Catfish	0.0	0.0	0.0	1
4ACUB010.96	Cub Creek near Rt.40 gaging station	9/13/1999	1	Bluegill Sunfish	8.3	8.3	8.3	1
4ACUB010.96	Cub Creek near Rt.40 gaging station	6/21/2006	2	Carp	145.0	763.4	454.2	2
4ACUB010.96	Cub Creek near Rt.40 gaging station	6/21/2006	1	Channel Catfish	113.7	113.7	113.7	1

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4ACUB010.96	Cub Creek near Rt.40 gaging station	9/13/1999-6/21/2006	2	Redbreast Sunfish	3.8	151.1	77.4	2
4ACUB010.96	Cub Creek near Rt.40 gaging station	9/13/1999-6/21/2006	2	Redhorse Sucker	8.4	195.5	101.9	2
4AFRV010.99	Falling River near Rt. 643 gaging station	8/26/1999	1	Redbreast Sunfish	0.2	0.2	0.2	1
4AFRV010.99	Falling River near Rt. 643 gaging station	8/26/1999	1	Redhorse Sucker	0.2	0.2	0.2	1
4AROA096.62	Roanoke River near Brookneal (site #74)	5/9/2000	2	Striped Bass	416.7	675.9	546.3	2
4AROA097.07	Roanoke River near Brookneal	4/18/2006	1	Black Crappie	109.2	109.2	109.2	1
4AROA097.07	Roanoke River near Brookneal	10/26/1998	1	Bluegill Sunfish	19.6	19.6	19.6	1
4AROA097.07	Roanoke River near Brookneal	2/9/1993-4/18/2006	11	Carp	82.7	834.9	431.1	11
4AROA097.07	Roanoke River near Brookneal	10/26/1998-4/18/2006	11	Channel Catfish	51.6	331.9	121.0	11
4AROA097.07	Roanoke River near Brookneal	10/26/1998	1	Flathead Catfish	144.7	144.7	144.7	1
4AROA097.07	Roanoke River near Brookneal	4/24/2002	1	Gizzard Shad	491.0	491.0	491.0	1
4AROA097.07	Roanoke River near Brookneal	10/26/1998-4/24/2002	2	Quillback Carpsucker	144.5	174.2	159.4	2
4AROA097.07	Roanoke River near Brookneal	10/26/1998	1	Redbreast Sunfish	64.1	64.1	64.1	1
4AROA097.07	Roanoke River near Brookneal	2/9/1993-4/18/2006	13	Redhorse Sucker	4.6	560.0	165.7	11
4AROA097.07	Roanoke River near Brookneal	10/26/1998-4/24/2002	4	Smallmouth Bass	79.5	156.1	123.2	4
4AROA097.07	Roanoke River near Brookneal	10/26/1998-4/24/2002	4	Spotted Bass	50.9	91.2	68.2	4
4AROA097.07	Roanoke River near Brookneal	2/9/1993-4/21/2006	30	Striped Bass	75.8	1906.0	568.8	29
4AROA097.07	Roanoke River near Brookneal	2/9/1993	6	Walleye	4.5	62.5	27.6	5
4AROA097.07	Roanoke River near Brookneal	2/9/1993-4/24/2002	11	White Perch	7.5	323.8	127.1	11
4AROA108.09	Roanoke River near Long Island	10/20/1998	1	Bluegill Sunfish	12.9	12.9	12.9	1
4AROA108.09	Roanoke River near Long Island	2/9/1993-4/19/2006	20	Carp	294.7	2724.5	968.0	20
4AROA108.09	Roanoke River near Long Island	2/9/1993-4/19/2006	17	Channel Catfish	45.5	761.4	285.3	17
4AROA108.09	Roanoke River near Long Island	10/20/1998-10/21/1998	6	Flathead Catfish	57.3	2451.6	757.7	6
4AROA108.09	Roanoke River near Long Island	10/20/1998	1	Redbreast Sunfish	23.1	23.1	23.1	1

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4AROA108.09	Roanoke River near Long Island	10/20/1998-4/19/2006	3	Redhorse Sucker	381.2	419.3	399.1	3
4AROA108.09	Roanoke River near Long Island	5/5/1993-4/19/2006	12	Smallmouth Bass	27.4	716.6	155.5	12
4AROA108.09	Roanoke River near Long Island	2/9/1993-10/20/1998	5	Spotted Bass	37.1	177.8	112.2	5
4AROA108.09	Roanoke River near Long Island	5/5/1993	2	Striped Bass	550.2	772.4	661.3	2
4AROA108.09	Roanoke River near Long Island	2/9/1993-5/12/1993	10	Sunfish	1.5	125.9	46.3	10
4AROA108.09	Roanoke River near Long Island	2/9/1993	3	Walleye	111.6	157.1	129.2	3
4AROA108.09	Roanoke River near Long Island	10/20/1998	1	White Perch	144.3	144.3	144.3	1
4AROA117.09	Roanoke River near Taber	10/27/1999	1	Channel Catfish	345.0	345.0	345.0	1
4AROA117.09	Roanoke River near Taber	10/20/1999	1	Redbreast Sunfish	99.5	99.5	99.5	1
4AROA117.09	Roanoke River near Taber	10/27/1999	1	Redhorse Sucker	307.9	307.9	307.9	1
4AROA117.09	Roanoke River near Taber	10/20/1999	1	Spotted Bass	106.5	106.5	106.5	1
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	1	Bluegill Sunfish	31.5	31.5	31.5	1
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	1	Carp	300.6	300.6	300.6	1
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	4	Channel Catfish	95.2	647.2	262.6	4
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	1	Flathead Catfish	58.1	58.1	58.1	1
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	1	Redbreast Sunfish	8.3	8.3	8.3	1
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	1	Redhorse Sucker	275.6	275.6	275.6	1
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	3	Smallmouth Bass	38.5	95.8	70.0	3
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	1	Spotted Bass	30.8	30.8	30.8	1
4AROA125.59	Roanoke River downstream Altavista	10/22/1998	1	Walleye	336.5	336.5	336.5	1
4ABOR012.18	Big Otter River near Rt. 682 gaging station	8/19/1999	1	Redbreast Sunfish	4.1	4.1	4.1	1

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4ABOR012.18	Big Otter River near Rt. 682 gaging station	8/19/1999	1	Redhorse Sucker	60.6	60.6	60.6	1
4ABOR012.18	Big Otter River near Rt. 682 gaging station	8/19/1999	1	Roanoke Hogsucker	0.6	0.6	0.6	1
4ALOR007.94	Little Otter River near Rt.784, below Bedford	5/30/2002	1	Bluehead Chub	21.3	21.3	21.3	1
4ALOR007.94	Little Otter River near Rt.784, below Bedford	8/17/1999	1	Carp	68.3	68.3	68.3	1
4ALOR007.94	Little Otter River near Rt.784, below Bedford	8/17/1999-5/30/2002	2	Redbreast Sunfish	3.1	8.2	5.7	2
4ALOR007.94	Little Otter River near Rt.784, below Bedford	8/17/1999	1	Redhorse Sucker	28.5	28.5	28.5	1
4ALOR007.94	Little Otter River near Rt.784, below Bedford	8/17/1999	1	Smallmouth Bass	54.8	54.8	54.8	1
4ALOR007.94	Little Otter River near Rt.784, below Bedford	5/30/2002	1	White Sucker				0
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	6/10/2002-6/20/2006	9	Carp	7.0	995.8	397.6	9
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	6/10/2002-6/20/2006	5	Channel Catfish	25.0	149.9	87.6	5
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	6/20/2006	1	Gizzard Shad	30.4	30.4	30.4	1
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	6/10/2002	1	Golden Redhorse Sucker	83.1	83.1	83.1	1
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	6/10/2002-6/20/2006	3	Redbreast Sunfish	37.7	84.2	55.1	3
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	6/20/2006	2	Redhorse Sucker	47.5	105.5	76.5	2
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	6/20/2006	1	Rock Bass	94.3	94.3	94.3	1
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	6/20/2006	1	Smallmouth Bass	223.5	223.5	223.5	1
4AROA137.00	Roanoke River near Leesville Tail Race	10/23/1998	1	Bluegill Sunfish	14.4	14.4	14.4	1
4AROA137.00	Roanoke River near Leesville Tail Race	10/23/1998	1	Carp	56.1	56.1	56.1	1

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4AROA137.00	Roanoke River near Leesville Tail Race	10/23/1998	3	Channel Catfish	12.3	107.1	51.9	3
4AROA137.00	Roanoke River near Leesville Tail Race	10/23/1998	1	Flathead Catfish	299.9	299.9	299.9	1
4AROA137.00	Roanoke River near Leesville Tail Race	10/23/1998	1	Redbreast Sunfish	1.4	1.4	1.4	1
4AROA137.00	Roanoke River near Leesville Tail Race	10/23/1998	1	Redhorse Sucker	160.5	160.5	160.5	1
4AROA137.00	Roanoke River near Leesville Tail Race	10/23/1998	1	Smallmouth Bass	14.4	14.4	14.4	1
4AGSE013.78	Goose Creek near Rt. 732 gaging station	8/18/1999	1	Redbreast Sunfish	4.2	4.2	4.2	1
4AGSE013.78	Goose Creek near Rt. 732 gaging station	8/18/1999	1	Roanoke Hogsucker				0
4AGSE013.78	Goose Creek near Rt. 732 gaging station	8/18/1999	1	Rock Bass				0
4AGSE013.78	Goose Creek near Rt. 732 gaging station	8/18/1999	1	Smallmouth Bass	0.2	0.2	0.2	1
4AGSF002.16	South Fork Goose Creek near Rt. 607 bridge, Montvale	5/30/2002	1	Bluehead Chub	10.0	10.0	10.0	1
4AGSF002.16	South Fork Goose Creek near Rt. 607 bridge, Montvale	5/30/2002	1	White Sucker	12.8	12.8	12.8	1
4AROA140.66	Roanoke River (Leesville Lake - Lower Lake site)	9/24/1999	1	Bluegill Sunfish	1.5	1.5	1.5	1
4AROA140.66	Roanoke River (Leesville Lake - Lower Lake site)	9/24/1999-7/20/2006	4	Carp	5.9	17.4	11.3	4
4AROA140.66	Roanoke River (Leesville Lake - Lower Lake site)	11/19/1998	1	Channel Catfish	45.0	45.0	45.0	1
4AROA140.66	Roanoke River (Leesville Lake - Lower Lake site)	11/19/1998-9/24/1999	2	Gizzard Shad	6.9	12.7	9.8	2
4AROA140.66	Roanoke River (Leesville Lake - Lower Lake site)	11/19/1998-7/20/2006	3	Largemouth Bass	1.9	9.5	4.5	3
4AROA140.66	Roanoke River (Leesville Lake - Lower Lake site)	11/19/1998-12/10/1998	2	Striped Bass	25.9	52.1	39.0	2

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4AROA140.66	Roanoke River (Leesville Lake - Lower Lake site)	11/19/1998	1	Walleye	4.8	4.8	4.8	1
4AROA140.66	Roanoke River (Leesville Lake - Lower Lake site)	11/19/1998	1	White Bass	40.0	40.0	40.0	1
4AROA198.75	Smith Mountain Lake - Back Creek	4/27/2004	1	Striped Bass	94.1	94.1	94.1	1
4AROA199.20	Roanoke River just upstream Niagara Dam	7/13/1993-7/19/2006	11	Carp	84.2	832.2	373.0	11
4AROA199.20	Roanoke River just upstream Niagara Dam	7/13/1993	20	Redbreast Sunfish	13.9	80.1	39.0	20
4AROA199.20	Roanoke River just upstream Niagara Dam	7/13/1993-7/19/2006	11	Redhorse Sucker	11.7	317.7	120.7	11
4AROA199.20	Roanoke River just upstream Niagara Dam	7/13/1993	5	Smallmouth Bass	62.3	237.0	135.9	5
4AROA199.60	Roanoke River above Niagara Dam	10/18/1999	1	Carp	488.9	488.9	488.9	1
4AROA199.60	Roanoke River above Niagara Dam	10/18/1999	1	Largemouth Bass	271.9	271.9	271.9	1
4AROA199.60	Roanoke River above Niagara Dam	10/18/1999	1	Redbreast Sunfish	26.5	26.5	26.5	1
4AROA199.60	Roanoke River above Niagara Dam	10/18/1999	1	Redhorse Sucker	100.5	100.5	100.5	1
4AROA199.78	Roanoke River just above Niagara Dam	8/21/2002	4	Carp	163.1	438.9	249.3	4
4AROA199.78	Roanoke River just above Niagara Dam	8/21/2002	2	Golden Redhorse Sucker	63.1	109.9	86.5	2
4AROA199.78	Roanoke River just above Niagara Dam	8/21/2002	1	Largemouth Bass	23.7	23.7	23.7	1
4AROA199.78	Roanoke River just above Niagara Dam	8/21/2002	1	Redbreast Sunfish	31.0	31.0	31.0	1
4ATKR000.17	Tinker Creek near Rt. 24	8/18/2004	1	Fantail Darter	214.0	214.0	214.0	1
4ATKR000.17	Tinker Creek near Rt. 24	5/29/2002	1	Golden Redhorse Sucker	221.1	221.1	221.1	1
4ATKR000.17	Tinker Creek near Rt. 24	5/29/2002	1	Redbreast Sunfish	23.2	23.2	23.2	1
4ATKR000.17	Tinker Creek near Rt. 24	8/18/2004	2	Riverweed Darter	91.0	99.6	95.3	2

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4ATKR000.17	Tinker Creek near Rt. 24	8/18/2004	1	Roanoke Darter	134.4	134.4	134.4	1
4ATKR000.17	Tinker Creek near Rt. 24	5/29/2002	1	Rock Bass	49.4	49.4	49.4	1
4ATKR000.17	Tinker Creek near Rt. 24	5/29/2002	1	White Sucker	32.2	32.2	32.2	1
4ATKR000.69	Tinker Creek near Rt. 24, Roanoke/Vinton line	8/18/1999	1	Redbreast Sunfish	20.3	20.3	20.3	1
4ATKR000.69	Tinker Creek near Rt. 24, Roanoke/Vinton line	8/18/1999	1	Redhorse Sucker	37.3	37.3	37.3	1
4ATKR000.69	Tinker Creek near Rt. 24, Roanoke/Vinton line	8/18/1999	1	Rock Bass	26.3	26.3	26.3	1
4AGLA005.04	Glade Creek near Rt. 636 bridge, Bonsack	7/24/2002	1	Roanoke Bass	1.4	1.4	1.4	1
4AGLA005.04	Glade Creek near Rt. 636 bridge, Bonsack	7/24/2002	2	White Sucker	0.4	2.0	1.2	2
4AROA202.20	Roanoke River near 13th Street bridge	8/17/2004	2	Margined Madtom	340.1	483.6	411.9	2
4AROA202.20	Roanoke River near 13th Street bridge	7/22/2002	1	Redbreast Sunfish	38.7	38.7	38.7	1
4AROA202.20	Roanoke River near 13th Street bridge	8/17/2004-9/16/2004	2	Riverweed Darter	350.4	350.4	350.4	1
4AROA202.20	Roanoke River near 13th Street bridge	8/17/2004-9/16/2004	2	Roanoke Darter	382.1	543.7	462.9	2
4AROA202.20	Roanoke River near 13th Street bridge	7/22/2002	1	Shorthead Redhorse Sucker	32.7	32.7	32.7	1
4AROA202.20	Roanoke River near 13th Street bridge	7/22/2002	1	White Sucker	44.1	44.1	44.1	1
4AROA206.80	Roanoke River near Wasena Park at Rt. 11 bridge	7/8/1999	1	Black Jumprock Sucker	35.3	35.3	35.3	1
4AROA206.80	Roanoke River near Wasena Park at Rt. 11 bridge	8/22/2002-7/19/2006	5	Carp	85.0	688.2	420.4	4
4AROA206.80	Roanoke River near Wasena Park at Rt. 11 bridge	7/22/2002-7/19/2006	2	Golden Redhorse Sucker	44.7	95.7	70.2	2

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4AROA206.80	Roanoke River near Wasena Park at Rt. 11 bridge	7/8/1999-8/22/2002	2	Redbreast Sunfish	30.3	38.7	34.5	2
4AROA206.80	Roanoke River near Wasena Park at Rt. 11 bridge	7/8/1999	1	Rock Bass	130.5	130.5	130.5	1
4AROA206.80	Roanoke River near Wasena Park at Rt. 11 bridge	8/22/2002	1	Smallmouth Bass	43.3	43.3	43.3	1
4AROA206.80	Roanoke River near Wasena Park at Rt. 11 bridge	7/19/2006	1	White Sucker	43.4	43.4	43.4	1
4APEE000.49	Peters Creek	5/29/2002	1	Redbreast Sunfish	44.8	44.8	44.8	1
4APEE000.49	Peters Creek	5/29/2002	1	Rock Bass	57.0	57.0	57.0	1
4APEE000.49	Peters Creek	5/29/2002	1	White Sucker	21.4	21.4	21.4	1
4APEE001.04	Peters Creek, Roanoke at Shenandoah Ave. bridge	7/6/1999	1	Redbreast Sunfish	33.5	33.5	33.5	1
4APEE001.04	Peters Creek, Roanoke at Shenandoah Ave. bridge	7/6/1999	1	Redhorse Sucker	29.3	29.3	29.3	1
4APEE001.04	Peters Creek, Roanoke at Shenandoah Ave. bridge	7/6/1999	1	Rock Bass	68.2	68.2	68.2	1
4AMSN000.60	Mason Creek near A.R. Burton Tech.	7/7/1999	1	Redbreast Sunfish	8.7	8.7	8.7	1
4AMSN000.60	Mason Creek near A.R. Burton Tech.	7/7/1999	1	Redhorse Sucker	2.5	2.5	2.5	1
4AMSN000.60	Mason Creek near A.R. Burton Tech.	7/7/1999	1	Rock Bass	30.0	30.0	30.0	1
4AMSN000.60	Mason Creek near A.R. Burton Tech.	7/7/1999	1	Smallmouth Bass	22.2	22.2	22.2	1
4AROA212.99	Roanoke River, Salem near Rt. 11 bridge	7/7/1999	1	Black Jumprock Sucker	9.7	9.7	9.7	1
4AROA212.99	Roanoke River, Salem near Rt. 11 bridge	7/7/1999	1	Redbreast Sunfish	9.9	9.9	9.9	1
4AROA212.99	Roanoke River, Salem near Rt. 11 bridge	7/7/1999	1	Rock Bass	13.1	13.1	13.1	1

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4AROA216.33	Roanoke River below Koppers, Salem	10/19/1999	1	Carp	192.3	192.3	192.3	1
4AROA216.33	Roanoke River below Koppers, Salem	7/23/2002	2	Golden Redhorse Sucker	9.6	9.8	9.7	2
4AROA216.33	Roanoke River below Koppers, Salem	10/19/1999-7/23/2002	2	Redbreast Sunfish	5.8	16.7	11.3	2
4AROA216.33	Roanoke River below Koppers, Salem	10/19/1999	1	Redhorse Sucker	34.7	34.7	34.7	1
4AROA216.33	Roanoke River below Koppers, Salem	10/19/1999	1	Rock Bass	4.4	4.4	4.4	1
4AROA216.33	Roanoke River below Koppers, Salem	10/19/1999	1	Smallmouth Bass	21.5	21.5	21.5	1
4AROA216.33	Roanoke River below Koppers, Salem	7/23/2002	1	White Sucker	2.1	2.1	2.1	1
4AROA217.23	Roanoke River near Green Hill Park	8/18/2004	1	Fantail Darter	44.7	44.7	44.7	1
4AROA217.23	Roanoke River near Green Hill Park	8/18/2004	3	Margined Madtom	29.9	424.3	162.3	3
4AROA217.23	Roanoke River near Green Hill Park	8/18/2004	1	Riverweed Darter	18.9	18.9	18.9	1
4AROA217.23	Roanoke River near Green Hill Park	8/18/2004	2	Roanoke Darter	17.5	29.6	23.6	2
4AROA219.99	Roanoke River near Glenvar	6/17/1993	9	Bluehead Chub	1.0	87.9	14.0	9
4AROA219.99	Roanoke River near Glenvar	5/29/2002	1	Northern Hogsucker	20.3	20.3	20.3	1
4AROA219.99	Roanoke River near Glenvar	6/16/1993-5/29/2002	11	Redbreast Sunfish	0.4	6.6	2.7	11
4AROA219.99	Roanoke River near Glenvar	6/16/1993	5	Redhorse Sucker	4.2	32.0	16.0	5
4AROA219.99	Roanoke River near Glenvar	6/16/1993-5/29/2002	11	Rock Bass	0.4	33.0	11.2	11
4AROA219.99	Roanoke River near Glenvar	6/16/1993-6/17/1993	5	Smallmouth Bass	8.6	17.7	14.2	5
4ARSF004.63	South Fork Roanoke River near Rt. 636	10/15/1999	1	Redbreast Sunfish	3.8	3.8	3.8	1
4ARSF004.63	South Fork Roanoke River near Rt. 636	10/15/1999	1	Redhorse Sucker	3.0	3.0	3.0	1
4ARSF004.63	South Fork Roanoke River near Rt. 636	10/15/1999	1	Rock Bass	2.9	2.9	2.9	1

Station ID	Station Description	Period of Record	Date Count	Fish Species	Min. TPCBs (ug/kg)	Max. TPCBs (ug/kg)	Avg. TPCBs (ug/kg)	Sample Count
4ARSF011.52	South Fork Roanoke River	7/14/1993	10	Redbreast Sunfish	0.3	3.8	1.3	7
4ARSF011.52	South Fork Roanoke River	7/14/1993	5	Redhorse Sucker	0.9	8.0	4.4	5
4ARSF011.52	South Fork Roanoke River	7/14/1993	10	Rock Bass	1.6	32.7	7.0	10
4ARSF011.52	South Fork Roanoke River	7/14/1993	3	Smallmouth Bass	2.7	7.6	5.3	3
4ARSF011.52	South Fork Roanoke River	7/14/1993	10	White Sucker	1.7	26.7	11.5	9
4ARNF013.60	North Fork Roanoke River near Rt. 603	5/28/2002	1	Golden Redhorse Sucker	26.6	26.6	26.6	1
4ARNF013.60	North Fork Roanoke River near Rt. 603	10/14/1999	1	Green Sunfish				0
4ARNF013.60	North Fork Roanoke River near Rt. 603	7/13/1993-5/28/2002	11	Redbreast Sunfish	0.3	11.8	4.8	11
4ARNF013.60	North Fork Roanoke River near Rt. 603	7/13/1993-10/14/1999	11	Redhorse Sucker	0.3	15.7	6.7	9
4ARNF013.60	North Fork Roanoke River near Rt. 603	7/13/1993-10/14/1999	11	Rock Bass	1.7	14.8	7.3	11
4ARNF013.60	North Fork Roanoke River near Rt. 603	7/13/1993-10/14/1999	5	Smallmouth Bass	5.5	18.0	13.4	5
4ARNF013.60	North Fork Roanoke River near Rt. 603	7/13/1993-5/28/2002	10	White Sucker	0.9	3.4	1.7	8
4ACDN002.20	Cedar Run near Rt. 603	10/14/1999	1	Chub	37.0	37.0	37.0	1
4ACDN002.20	Cedar Run near Rt. 603	10/14/1999	1	Mixed Sunfish species	14.2	14.2	14.2	1
4ACDN002.53	Cedar Run near Rt. 603	5/28/2002	1	Bluehead Chub	5.1	5.1	5.1	1
4ACDN002.53	Cedar Run near Rt. 603	5/28/2002	1	Redbreast Sunfish	3.2	3.2	3.2	1

Table B-2. Sediment PCB monitoring data summary for the Roanoke River watershed

Station ID	Station Description	Period of Record	Date Count	Min. TPCB (ug/kg)	Max. TPCB (ug/kg)	Avg. TPCB (ug/kg)	Sample Count
4ABHA000.33	Buffalo Creek at Rt. 639	8/9/2007	1				0
4ABHE001.01	Beechtree Creek near Rt. 631	6/2/1999	1	10.16	10.16	10.16	1
4ABOR000.20	Big Otter River	6/2/1999	1	0.20	0.20	0.20	1
4ABOR003.18	Big Otter River	6/2/1999	1	0.13	0.13	0.13	1
4ABOR011.27	Big Otter River	6/3/1999	1	0.87	0.87	0.87	1
4ABOR012.18	Big Otter River near Rt. 682	6/3/1999	1	3.46	3.46	3.46	1
4ABOR024.91	Big Otter River near Road off Rt. 297	7/1/1999	1	0.58	0.58	0.58	1

Station ID	Station Description	Period of Record	Date Count	Min. TPCB (ug/kg)	Max. TPCB (ug/kg)	Avg. TPCB (ug/kg)	Sample Count
4ABWC001.00		7/30/1999	1	1.74	1.74	1.74	1
4ACBA000.12	Catawba Creek at Rt. 626	8/18/1999	1	1.83	1.83	1.83	1
4ACDN002.20	Cedar Run near Rt. 603	10/23/1998	1	12.83	12.83	12.83	1
4ACDN002.53	Cedar Run near Rt. 603	8/26/1999	1	6.14	6.14	6.14	1
4ACRE002.60	Childrey Creek at Rt. 632	8/3/1999	1	0.33	0.33	0.33	1
4ACUB002.21		6/3/1999	1	0.42	0.42	0.42	1
4ACUB010.96	Cub Creek near Rt. 40 gaging station (A)	6/2/1999	2	1.52	1.52	1.52	1
4ADIF002.02	Difficult Creek at Rt. 716	8/3/1999	1	3.74	3.74	3.74	1
4AFRV003.12	Falling River, downstream of lagoon outfall	8/27/1999	1				0
4AFRV010.99	Falling River near Rt. 643 gaging station	8/3/1999	1				0
4AGLA005.04	Glade Creek near Rt. 636 bridge, Bonsack	7/30/1999	1	0.34	0.34	0.34	1
4AGNE000.16	North Fork Goose Creek near Road Rt. 751	7/22/1999	1	0.27	0.27	0.27	1
4AGSE000.20	Goose Creek	7/30/1999	1				0
4AGSE013.78	Goose Creek near Rt. 732 gaging station	7/27/1999	1				0
4AGSF002.16	South Fork Goose Creek near Rt. 607 bridge, Montvale	7/30/1999	1	1.39	1.39	1.39	1
4AHIL000.60	Hill Creek at Rt. 633	8/4/2004	1				0
4AHTA000.80	Hunting Creek at Rt. 617	7/16/1999	1				0
4ALNA001.00	Long Branch at Rt. 633	8/3/1999	1	0.20	0.20	0.20	1
4ALOR007.94	Little Otter River near Rt. 784, below Bedford	8/3/2004	2	5.46	6.80	6.13	2
4ALYH000.02	Lynch Creek near Altavista Park	8/6/1997	1	849.90	849.90	849.90	1
4AMRC000.39	Mill Creek near Rt. 640	8/19/1999	1	0.67	0.67	0.67	1
4AMSN000.60	Mason Creek near A.R. Burton Tech.	6/19/1996	1	17.06	17.06	17.06	1
4APEE000.49	Peters Creek	8/6/1997	2	13.47	14.85	14.16	2
4APEE001.04	Peters Creek, Roanoke at Shenandoah Ave bridge	7/17/1997	1	41.74	41.74	41.74	1
4ARAB000.05	Reed Creek at Rt. 668 near Altavista	8/5/2004	1				0
4ARNF013.60	North Fork Roanoke River near Rt. 603	7/23/1999	3	0.29	3.11	2.06	3
4AROA049.40	Roanoke River	6/30/1999	1	3.04	3.04	3.04	1
4AROA052.69	Roanoke River, upstream Kerr Reservoir	5/28/2002	1	6.40	6.40	6.40	1
4AROA057.51	Roanoke River	7/26/1999	1	5.95	5.95	5.95	1
4AROA059.12	Roanoke River near Clover	7/23/1999	3	8.67	71.34	40.27	3
4AROA067.91	Roanoke River near Rt. 746 bridge	8/28/2007	2	6.81	109.55	58.18	2
4AROA068.79	Roanoke River	8/4/1999-9/13/1999	1	28.43	28.43	28.43	1
4AROA073.98	Roanoke River	7/22/1999	1	26.18	26.18	26.18	1
4AROA086.22	Roanoke River	8/5/2004	1	1.62	1.62	1.62	1
4AROA090.50		6/2/1999	1	65.27	65.27	65.27	1

Station ID	Station Description	Period of Record	Date Count	Min. TPCB (ug/kg)	Max. TPCB (ug/kg)	Avg. TPCB (ug/kg)	Sample Count
4AROA094.54	Downstream of RR Bridge,south side of sandy island	8/8/2007	1				0
4AROA094.67	North bank, downstream of Railroad (RR) Bridge	7/27/1999	1				0
4AROA094.68	Middle, just downstream of RR Bridge trestle	7/24/2002	1				0
4AROA095.90	South bank,across from sample #16 of Roanoke River	7/22/1999	1				0
4AROA095.95	North bank, downstream of last set of Hatchery Ponds	6/3/1999	1				0
4AROA096.05	North bank, upstream of rusty culvert	7/30/1999	1				0
4AROA096.10	South bank, upstream of Hatchery culvert	5/30/2002	1				0
4AROA096.34	Directly across from site of sample # 10	8/3/2004	1				0
4AROA096.35	Downstream of Hatchery Water Intake	7/30/1999	1				0
4AROA096.65	Downstream of Tanyard Branch	8/5/2004	1	2730.00	2730.00	2730.00	1
4AROA096.66	Downstream of lagoon outfall	8/28/2007	1				0
4AROA097.06	Middle Roanoke River at Rt. 501	6/2/1999	2				0
4AROA097.07	Roanoke River near Brookneal	2/5/2008	4	24.44	1050.95	689.08	3
4AROA097.21	Roanoke River	7/23/1996	1	4.92	4.92	4.92	1
4AROA097.76		8/4/2004	1	8.45	8.45	8.45	1
4AROA099.22	Roanoke River	8/4/2004	1	14.72	14.72	14.72	1
4AROA108.09	Roanoke River near Long Island	8/3/2004	1	3.44	3.44	3.44	1
4AROA112.72	Roanoke River	8/7/1996	1	16.61	16.61	16.61	1
4AROA117.09	Roanoke River near Taber	8/2/2004	1	6.69	6.69	6.69	1
4AROA117.49	Roanoke River	7/30/1999	2	0.00	0.00	0.00	2
4AROA122.31	Roanoke River	8/6/1997	1	25.09	25.09	25.09	1
4AROA125.59	Roanoke River downstream Altavista	8/3/2004	1	0.29	0.29	0.29	1
4AROA126.00	Roanoke River upstream of Big Otter River	7/13/1996	1	4.71	4.71	4.71	1
4AROA127.79		10/18/1999	1				0
4AROA128.98	Roanoke River at Rt. 668 near Altavista Park	6/10/2002	1	17.95	17.95	17.95	1
4AROA129.55		2/5/2008	1	1.29	1.29	1.29	1
4AROA129.95	Roanoke River near Rt. 29 bridge at Altavista	8/21/2002	1	15.62	15.62	15.62	1
4AROA131.55		7/29/1999	1	2.93	2.93	2.93	1
4AROA137.00	Roanoke River near Leesville Tail Race	8/3/2004	1				0
4AROA140.66	Roanoke River (Leesville Lake-Lower Lake site)	7/7/1999	1				0
4AROA198.75	Roanoke River upstream Back Creek	7/23/1999	1	5.34	5.34	5.34	1

Station ID	Station Description	Period of Record	Date Count	Min. TPCB (ug/kg)	Max. TPCB (ug/kg)	Avg. TPCB (ug/kg)	Sample Count
4AROA199.20		6/19/1996	2	37.23	47.35	42.29	2
4AROA199.60	Roanoke River above Niagara Dam	5/29/2002	1	133.37	133.37	133.37	1
4AROA199.68		7/29/1999	1	94.60	94.60	94.60	1
4AROA199.73		7/26/1999	1	41.50	41.50	41.50	1
4AROA199.78	Roanoke River just above Niagara Dam	6/2/1999	1	81.87	81.87	81.87	1
4AROA202.20	Roanoke River at 13th Street bridge	8/6/1999	2	43.83	77.84	60.83	2
4AROA206.80	Roanoke River at Wasena Park near Rt. 11 bridge	6/2/1999	2	1.94	11.65	6.79	2
4AROA212.99	Roanoke River, Salem near Rt. 11 bridge	7/15/1997	1	9.98	9.98	9.98	1
4AROA216.33	Roanoke River, Salem below Koppers	6/19/1996	1				0
4AROA216.34	Roanoke River	7/23/1996	1	2.19	2.19	2.19	1
4AROA217.23	Roanoke River near Green Hill Park	7/31/1997	1	0.55	0.55	0.55	1
4AROA219.99	Roanoke River near Glenvar	8/8/2007	1	1.53	1.53	1.53	1
4AROC001.00		7/15/1997	1	0.56	0.56	0.56	1
4AROC005.35	Roanoke Creek near Saxe	10/20/1999	1				0
4ARSF004.63	South Fork Roanoke River near Rt. 636	10/22/1998	1	1.57	1.57	1.57	1
4ARSF006.60	South Fork Roanoke River	7/13/1996	1	1.00	1.00	1.00	1
4ARSF011.52	South Fork Roanoke River	10/22/1998	1	0.66	0.66	0.66	1
4ASCE000.24	Sycamore Creek near Pocket Road	8/3/2004	1				0
4ASCE000.26		7/30/1999	1				0
4ASEN000.18	Seneca Creek near Rt. 704	8/8/2007	1	2.48	2.48	2.48	1
4ASSC002.85	Straightstone Creek near Rt. 761	8/8/2007	1				0
4ASYD000.01	Snyders Branch	8/17/1999-5/30/2002	1	7.57	7.57	7.57	1
4ATAB000.05	Tanyard Branch, downstream of lagoon	5/29/2002	1				0
4ATIP000.42	Turnip Creek near Road off Rt. 649	8/18/1999	1	3.70	3.70	3.70	1
4ATKR000.17	Tinker Creek near Rt. 24	8/5/1999-9/10/2007	3	26.45	101.90	74.03	3
4ATKR000.69	Tinker Creek near Rt. 24, Roanoke/Vinton line (A) -- !!!	7/15/1997	2	54.52	940.76	497.64	2
4AWPP000.60	Whipping Creek near Road off Rt. 614	9/15/1999-8/21/2002	1	0.88	0.88	0.88	1
4AXCN000.20	Unnamed Tributary at Rt. 29 Substation Altavista	2/5/2008	1	7.95	7.95	7.95	1
4AXXX001.30	Unnamed Tributary at Rt. 633 Green Hill	7/22/2002-8/17/2004	1				0
4AXXZ000.05	Unnamed Tributary, just west of Altavista STP -- !!!	7/8/1999-7/22/2002	1	82235.37	82235.37	82235.37	1
4AZZZ095.38	Unnamed tributary downstream of sample # 17	6/30/1999-5/28/2002	1	2.60	2.60	2.60	1

Station ID	Station Description	Period of Record	Date Count	Min. TPCB (ug/kg)	Max. TPCB (ug/kg)	Avg. TPCB (ug/kg)	Sample Count
4AZZZ096.27	Unnamed tributary across from Hatchery	5/29/2002-8/18/2004	1	6.23	6.23	6.23	1
4AZZZ096.71	Unnamed trib across from Tanyard Branch,south side	10/26/1998-4/24/2002	1	1.50	1.50	1.50	1
4AZZZ097.07	Unnamed trib near Rt. 501,south side	9/14/1999-8/4/2004	1	174.89	174.89	174.89	1
4AZZZ097.08	Unnamed trib near Rt. 501,north side	10/27/1998-9/10/2007	1	9.45	9.45	9.45	1

Table B-3. Water column PCB monitoring data summary for the Roanoke River watershed

Station ID	Period of Record	Flow Condition	Min. TPCB (pg/L)	Max. TPCB (pg/L)	Avg. TPCB (pg/L)	Sample Count
4ABOR000.62	10/26/2007	High	252.5	252.5	252.5	1
4ABOR000.62	8/21/2007	Low	115.4	115.4	115.4	1
4ABWC001.00	10/26/2007	High	559.2	559.2	559.2	1
4ACUB002.21	10/26/2007	High	12.9	12.9	12.9	1
4ACUB002.21	8/28/2007	Low	12.4	12.4	12.4	1
4ADFF002.02	8/28/2007	Low	3.8	3.8	3.8	1
4AFRV002.78	9/10/2007	Low	17.8	17.8	17.8	1
4AGND000.02	4/7/2008	High	613.2	613.2	613.2	1
4AGND000.02	3/3/2008	Low	155.3	155.3	155.3	1
4AGSE000.20	10/26/2007	High	343	343	343	1
4AGSE000.20	9/10/2007	Low	34.8	34.8	34.8	1
4ALYH000.17	5/9/2008	High	34672.5	34672.5	34672.5	1
4AROA059.12	12/1/2005-10/26/2007	High	1317	185397	62691.0333	3
4AROA059.12	10/21/2005-9/10/2007	Low	262	1632.1	947.05	2
4AROA067.91	12/1/2005-10/26/2007	High	991	1307	1149	2
4AROA067.91	10/21/2005-9/10/2007	Low	58	1340.1	699.05	2
4AROA090.50	10/26/2007	High	1624.8	1624.8	1624.8	1
4AROA090.50	8/8/2007	Low	1192.2	1192.2	1192.2	1
4AROA097.76	3/6/2008	High	4304.2	4304.2	4304.2	1
4AROA097.76	8/8/2007	Low	1118.1	1118.1	1118.1	1
4AROA108.09	9/10/2007	Low	1146.8	1146.8	1146.8	1
4AROA124.59	3/10/2008-5/9/2008	High	2908.8	4466.4	3687.6	2
4AROA127.79	8/9/2007	Low	147.7	147.7	147.7	1
4AROA129.55	10/26/2007-5/9/2008	High	388.2	766.3	577.25	2
4AROA129.55	8/8/2007	Low	72	72	72	1
4AROA131.55	5/9/2008	High	186.9	186.9	186.9	1
4AROA131.55	8/8/2007	Low	57.4	57.4	57.4	1
4AROA199.20	11/22/2005-4/7/2008	High	466	1588.1	1027.05	2
4AROA199.20	10/14/2005-3/3/2008	Low	53	1212.7	632.85	2

Station ID	Period of Record	Flow Condition	Min. TPCB (pg/L)	Max. TPCB (pg/L)	Avg. TPCB (pg/L)	Sample Count
4AROA202.20	4/7/2008	High	3043.9	3043.9	3043.9	1
4AROA202.20	3/3/2008	Low	1376.4	1376.4	1376.4	1
4AROA204.00	10/14/2005	Low	0	0	0	1
4AROA204.76	11/22/2005-4/7/2008	High	863	3013.9	1938.45	2
4AROA204.76	3/3/2008	Low	986.9	986.9	986.9	1
4AROA207.08	4/7/2008	High	641.8	641.8	641.8	1
4AROA207.08	3/3/2008	Low	363.4	363.4	363.4	1
4AROA212.17	4/7/2008	High	255.9	255.9	255.9	1
4AROA212.17	3/3/2008	Low	80.1	80.1	80.1	1
4AROA227.42	11/22/2005-4/7/2008	High	95.3	95.3	95.3	1
4AROA227.42	10/13/2005-3/3/2008	Low	57	106.6	81.8	2
4AROC001.00	10/26/2007	High	5.2	5.2	5.2	1
4AROC001.00	8/28/2007	Low	26.2	26.2	26.2	1
4ASCE000.26	8/27/2007	Low	28.6	28.6	28.6	1
4AXLN000.00	12/1/2007	High	1489097.7	1489097.7	1489097.7	1
Steel Dynamics	3/3/2008	Low	750.9	750.9	750.9	1

Table B-4. TSS monitoring data summary for the Roanoke River watershed

Station ID	Station Description	Period of Record	Date Count	Min. TSS (mg/L)	Max. TSS (mg/L)	Avg. TSS (mg/L)	Sample Count
4ABHA002.47	RTE 639 (Rockbarn Road)	8/12/2003-6/30/2005	12	3.0	58.0	10.4	12
4ABOR000.62	ROUTE 712 BRIDGE, NEAR CONFLUENCE WITH R	3/15/1990-10/26/2007	157	3.0	417.0	30.1	136
4ABOR012.18	STA #8 RT.644 BRIDGE (BEDFORD COUNTY)	8/19/1992-8/9/1993	2				0
4ABOR019.84	Upstream of Cobbs Creek Mouth	4/6/2004	1	5.0	5.0	5.0	1
4ABWC001.00	RTE 600	8/29/2007	1				0
4ACDN001.12	Rt. 723 Bridge	1/0/1900-1/0/1900	13	3.0	5.0	3.2	13
4ACRE002.52	CHILDREY CR RT. 632 BRIDGE	9/19/1990-2/26/2001	52	1.0	496.0	27.9	48
4ACUB002.21	RTE 649 (Coles Ferry Road)	8/28/2007-10/26/2007	2	10.0	31.0	20.5	2
4ACUB017.46	RED HOUSE ROAD	8/4/2003-6/27/2005	17	3.0	45.0	8.9	17
4ADFF002.02	RT. 716 BRIDGE	7/2/1990-8/28/2007	70	1.0	253.0	10.1	65
4AFRV002.78	Off Rt. 600 Below Brookneal STP	3/5/1990-9/10/2007	67	3.0	202.0	12.2	33
4AFRV010.99	NARANA GAGE RT. 643	7/12/2001-5/1/2007	36	3.0	45.0	5.6	36
4AGLA004.39	LAYMAN RD. (RT. 606)	8/8/2001-5/4/2005	24	3.0	65.0	8.5	24

Station ID	Station Description	Period of Record	Date Count	Min. TSS (mg/L)	Max. TSS (mg/L)	Avg. TSS (mg/L)	Sample Count
4AGND000.02	Below Riverland Road	3/3/2008-4/7/2008	2	3.0	13.0	8.0	2
4AGSE000.20	RT. 630 BRIDGE AT LEESVILLE	3/15/1990-10/26/2007	58	3.0	340.0	27.1	25
4AGSE015.07	Goose Creek	4/10/2006	1	9.0	9.0	9.0	1
4AGSF002.60	Rt 897 Bridge	6/25/2002	1	3.0	3.0	3.0	1
4AHTA000.77	Hunting Creek @ Rt. 617	8/4/2003-6/27/2005	12	3.0	20.0	8.6	12
4AHTA003.26	STATION 1 - CONNER LAKE (PORTION OF HUNT	8/3/1993-8/3/1993	2				0
4ALOR007.20	Little Otter River below Bedford	4/23/2007	1	10.0	10.0	10.0	1
4ALOR008.64	RT. 784 BRIDGE,BEDFORD CO	7/17/1996-6/6/2007	81	3.0	559.0	31.9	77
4ALYH000.00	Lynch Creek	10/20/2005	1	8.0	8.0	8.0	1
4ALYH000.17	Lynch Creek above last bridge @ boatramp	5/20/2008	1	3.0	3.0	3.0	1
4AMSN000.67	ROANOKE BOULEVARD BRIDGE	7/15/2003-11/7/2006	22	3.0	38.0	4.8	22
4APEE000.00	10 YARDS ABOVE CONFUENCE	8/26/1992-10/13/2005	2	14.0	14.0	14.0	1
4APEE001.04	SHENANDOAH AVENUE BRIDGE	7/26/1994-11/7/2006	55	3.0	30.0	7.0	41
4ARNF013.66	ROUTE 603 BRIDGE NEAR ELLETT - MONTGOMER	7/16/2003-5/9/2007	24	3.0	10.0	3.7	24
4AROA059.12	ROUTE 360 BRIDGE, EAST OF CLOVER	1/8/1990-10/26/2007	197	1.0	408.0	29.0	168
4AROA067.91	RT.746 BRIDGE (WATKINS BRIDGE) NEAR RAND	2/1/1990-10/26/2007	110	2.0	266.0	26.1	89
4AROA090.50	ROUTE 620 SOUTH OF BROOKNEAL	2/1/1990-10/26/2007	20	5.0	20.0	10.0	3
4AROA097.46	ROANOKE RIVER AT BROOKNEAL GAGE , RT. 50	1/24/1990-5/1/2007	182	3.0	239.0	23.8	174
4AROA097.76	Roanoke (Staunton) River	10/21/2005-3/6/2008	4	4.0	66.0	23.0	4
4AROA108.09	RT. 761 BRIDGE - MAIN CHANNEL OF ROANOKE	2/23/1993-5/1/2007	34	3.0	124.0	18.8	34
4AROA123.85	Old Mansion Bridge	10/21/2005	1	8.0	8.0	8.0	1
4AROA124.59	ROUTE 640 BRIDGE - CAMPBELL COUNTY	8/19/1999-5/9/2008	13	3.0	157.0	24.8	13
4AROA127.79	ROA.RI.POWER LNE.CROSSING 1.15 MI.NE RT	8/9/2007	1	4.0	4.0	4.0	1
4AROA128.21	Roaonke River near Lane East Landfill	10/20/2005	1	4.0	4.0	4.0	1
4AROA128.94	Roaonke River near Lane West Landfill	10/20/2005	1	4.0	4.0	4.0	1
4AROA128.97	Alta Vista Water Intake	10/20/2005	1	5.0	5.0	5.0	1
4AROA129.55	ROUTE 29 BRIDGE, AT GAGE - PITTSYLVANIA	2/1/1990-5/9/2008	116	3.0	208.0	14.1	71

Station ID	Station Description	Period of Record	Date Count	Min. TSS (mg/L)	Max. TSS (mg/L)	Avg. TSS (mg/L)	Sample Count
4AROA131.55	ROUTE 29 BRIDGE BYPASS, ALTAVISTA	8/8/2007-5/9/2008	3	5.0	69.0	30.0	3
4AROA137.00	Roanoke River near Leesville Tail Race	10/20/2005	1	3.0	3.0	3.0	1
4AROA140.66	LEESVILLE LK #1A-TOP #1B-MIDDLE #1C-BOT	4/16/1990-6/12/2003	105	3.0	46.0	6.6	90
4AROA199.20	BLUE RIDGE PARKWAY BR. BELOW ROANOKE	7/12/2005-4/7/2008	13	3.0	93.0	14.4	12
4AROA200.06	Roanoke River downstream of Tinker Creek	10/13/2005	1	7.0	7.0	7.0	1
4AROA202.20	13TH. ST. BRIDGE ABOVE ROANOKE STP	1/10/1990-4/7/2008	199	1.0	744.0	19.4	187
4AROA204.76	Roanoke River at Roanoke City	10/13/2005-4/7/2008	4	3.0	40.0	18.3	3
4AROA205.73	Franklin Road Bridge, Roanoke, VA	7/21/2003-11/7/2006	21	3.0	10.0	4.8	21
4AROA207.08	Little Otter River below Bedford	10/13/2005-4/7/2008	3	5.0	46.0	19.3	3
4AROA212.17	ROUTE 11 BRIDGE BELOW EATON, INC.	4/16/1990-4/7/2008	144	2.0	776.0	18.4	134
4AROA215.13	Mill Lane Bridge, Salem, VA	7/15/2003-10/13/2005	13	3.0	108.0	11.5	13
4AROA219.99	ROUTE 612 BRIDGE ABOVE SALEM AT WABUM	10/13/2005	1	14.0	14.0	14.0	1
4AROA227.42	RT. 773 AT GAGING STA. IN LAFAYETTE	1/10/1990-4/7/2008	195	1.0	366.0	13.5	186
4AROC001.00	Roanoke Cr. @ Roanoke Station Rd.	8/28/2007-10/26/2007	2	4.0	11.0	7.5	2
4AROC005.35	ROANOKE CREEK AT THE CONFLUENCE WITH TWI	8/28/2001-6/14/2007	15	3.0	8.0	4.7	15
4ARSF000.88	RT. 460/11 BRIDGE BELOW GREEN HILL, INC.	7/7/2005-11/27/2006	9	3.0	17.0	5.0	9
4ARSF007.29	Upstream of US 11/460 in Shawsville	4/28/2005-4/28/2005	2	3.0	3.0	3.0	1
4ARSF011.73	RT. 637 BRIDGE AT GAGE	7/22/1999-11/27/2006	22	3.0	29.0	4.6	22
4ASCE000.26	ROUTE 924 BRIDGE - PITTSYLVANIA COUNTY	3/15/1990-8/27/2007	67	3.0	41.0	7.7	35
4ASEN000.40	ROUTE 704 BRIDGE, ABOVE LONG ISLAND	3/15/1990-5/1/2007	69	3.0	104.0	7.0	35
4ATIP002.55	TURNIP CREEK, RT. 619 BRIDGE	9/29/1994-6/10/2003	47	3.0	338.0	19.1	45
4ATKR000.69	RT. 24 BRIDGE ABOVE TOWN OF VINTON	2/5/1990-5/9/2007	181	3.0	325.0	12.8	167
4AWPP002.53	WHIPPING CREEK, RT 633	8/12/2003-6/30/2005	12	3.0	20.0	5.1	12
4AXLN000.00	X-Trib of Roanoke (BGF)	10/20/2005	1	12.0	12.0	12.0	1

Appendix C:
Roanoke River PCB TMDL Stormwater Sites

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Table C-1. Sites represented as stormwater discharges in the Roanoke River watershed

Permit ID	Facility Name	Area (acres)
VAR051315	A D Weddle Company Inc	7.31
	Abbott Labs	36.35
	Accellent Cardiology, Inc.-Main Bldg	3.97
	Accellent Cardiology, Inc.-West Bldg	3.00
	Advanced Metal Finishing	0.92
	Allied Tool & Machine Co., of Virginia	1.26
VAR051570	Altec Industries Inc	40.56
VAR050027	Auto Salvage and Sales Incorporated	1.67
	BGF Industries	28.07
VA0001678	Burlington Industries - Hurt	138.41
VAR050174	Carbone of America Corporation	7.71
VAR050717	Cycle Systems Incorporated	5.52
VA0083402	Dominion - Altavista	8.81
VA0083097	Dominion - Clover	934.02
VA0083399	Dominion - Pittsylvania	8.77
VAR051460	Dynax America Corp USA	16.05
	Fabricated Metals Ind., Inc.	5.97
VAR050251	Federal Mogul Corp - Blacksburg	38.14
	Graham Packaging Plastic Products	18.97
VAR050150	Graham White Manufacturing Company	22.49
VAR520200	Hancock Rack Syst dba New Millenium Building Syst	2.58
VAR050176	John W Hancock Jr LLC dba New Millennium Bldg Syst	2.78
VAR050741	Medeco Security Locks Inc	16.26
VAR051352	MRSWA Solid Waste Transfer Station MRF	137.42
VAR050436	Norfolk Southern Corp - Roadway Material Yard	1.50
VAR050762	Novozymes Biologicals Inc	1.72
VAR050762	Novozymes Biologicals, Inc.	1.90
	NSW	7.01
VAR050275	Old Dominion Auto Salvage	10.49
VAR050520	O'Neal Steel Inc	19.87
	Packaging Corp. of America	3.00
	Packaging Corp. of America	3.71
VAR050747	Parts Unlimited	5.23
	Patterson Avenue CDD Landfill - Norfolk Southern Railway	19.84
VAR051478	Precision Steel	5.23
VAR050522	Progress Rail Services Corp - Roanoke	12.08
VAR050273	Ralph Smith Inc	2.03
	Roanoke Regional Landfill	104.15
VAR050526	RR Donnelley and Sons Company - Roanoke	133.66
	Sanitary Landfill at Mowles Spring Park (closed)	36.98
	Schrader Bridgeport	9.73
VAR050530	Shenandoah Auto Parts	1.87
VAR051262	Shorewood Packaging Corporation - Roanoke	4.07
VAR050775	Star City Auto Parts Inc	1.05
VA0001589	Steel Dynamics	16.61
	Tecton Products, Roanoke VA	19.96

Permit ID	Facility Name	Area (acres)
	The Roanoke Times	2.51
VAR050135	Virginia Scrap Iron & Metal Company Inc	8.15
VAR051492	Virginia Transformer Corp	8.95
VAR520005	Vishay Vitramon Inc	21.57
VAR050208	Walker Machine and Foundry Corp	7.27
	Wise Recycling, LLC	0.74
VAR050204	Wolverine Advanced Materials	13.48
VAR050340	Wolverine Advanced Materials - Blacksburg	12.70
VAR050515	Yokohama Tire Corp	56.12

Appendix D:
Roanoke River PCB TMDL Model Parameters

LIST OF TABLES

Table D-1. Roanoke River watershed model hydrologic parameters and ranges

Model Parameter	Parameter description	Value range
LZSN	lower zone nominal soil moisture storage (in)	5.0–5.4
INFILT	index to the infiltration capacity of the soil (in/hr)	0.022–0.250
KVARY	variable groundwater recession (1/in)	0.2–0.3
AGWRC	base groundwater recession (none)	0.986–0.990
PETMAX	air temperature below which evapotranspiration is reduced (deg F)	40
PETMIN	air temperature below which evapotranspiration is set to 0 (deg F)	35
INFEXP	exponent in the infiltration equation (none)	2
INFILD	ration between the maximum and mean infiltration capacities (none)	2
DEEPFR	fraction of groundwater inflow that will enter deep groundwater (none)	0.12–0.16
BASETP	fraction of remaining potential evapotranspiration that can be satisfied from baseflow (none)	0.03–0.04
AGWETP	fraction of remaining potential evapotranspiration that can be satisfied from active groundwater (none)	0
CEPSC	interception storage capacity (in)	0.08–0.22
UZSN	upper zpne nominal storage (in)	0.50–0.65
NSUR	Manning's n for the assumed overland flow plane (none)	0.25
INTFW	interflow parameter (none)	1.0–2.0
IRC	interflow recession parameter (none)	0.37–0.55
LZETP	lower zone evapotranspiration parameter (none)	0.20–0.65

Table D-2. Roanoke River watershed model land sediment parameters and ranges

Model Parameter	Parameter Description	Value range
SMPF	Supporting management practice factor (P factor)	0.2–0.75
KRER	Coefficient in the soil detachment equation	0.29–0.32
JRER	Exponent in the soil detachment equation	2
AFFIX	Fraction by which detached sediment storage decreases each day as a result of soil compaction	0.04
COVER	Fraction of land surface that is shielded from rainfall erosion	0.15–0.88
NVSI	Rate at which sediment enters detached storage from the atmosphere	0
KSER	Coefficient in the detached sediment washoff equation	0.5–4.5
JSER	Exponent in the detached sediment washoff equation	2
KGER	Coefficient in the matrix soil scour equation	0
JGER	Exponent in the matrix soil scour equation	2.5
ACCSDP	Rate at which solids accumulate on the land surface	0.07
REMSDP	Fraction of solids storage that is removed each day when there is no runoff	0.066
SED-SURO	Background concentration associated with surface flow (mg/L)	20
SED-IFWO	Background concentration associated with interflow outflow (mg/L)	3
SED-AGWO	Background concentration associated with groundwater outflow (mg/L)	3
SED_1	Fraction of total sediment from land that is sediment class sand	0.04
SED_2	Fraction of total sediment from land that is sediment class silt	0.616–0.706
SED_3	Fraction of total sediment from land that is sediment class clay	0.254–0.344

Table D-3. Roanoke River watershed model stream sediment parameters and ranges

Model Parameter	Parameter Description	Particle class	Value range
SEDFRAC	Initial sediment particle class fractions (by weight) in	Sand	0.1–0.977

Model Parameter	Parameter Description	Particle class	Value range
	bed material	Silt	0.009–0.45
		Clay	0.013–0.45
DB50/D	Median/effective diameter of the sediment particle class	Sand	0.00492
		Silt	0.00028
		Clay	0.00002
W	Particle fall velocity in still water (in/s)	Sand	0.0866
		Silt	0.000118
		Clay	0.000002
RHO	Particle density (gm/cm3)	Sand	2.6
		Silt	2.3
		Clay	2
KSAND	Coefficient in sandload power function		0.01
EXPSND	Exponent in sandload power function		1
TAUCD	Critical bed shear stress for deposition (lb/ft2)		0.01
TAUCS	Critical bed shear stress for scour (lb/ft2)		0.0002–4.08
M	Erodibility coefficient of the cohesive particles (lb/ft2/day)		0.01

Table D-4. Roanoke River watershed stream physical parameter values

Reach ID	Bed width (ft)	Initial bed depth (ft)	Porosity
1000	74.4	2.5	0.45
1001	16	2.5	0.45
1002	14.3	1	0.45
1003	73.6	2	0.45
1004	73.6	2	0.45
1005	73.4	2.5	0.45
1006	71.2	2	0.45
1007	7.8	2.5	0.45
1008	7.7	1.5	0.45
1009	25	2.5	0.45
1010	22.8	2	0.45
1011	20.6	2.5	0.45
1012	14.3	1.5	0.45
1013	13.1	2	0.45
1014	11.8	2	0.45
1015	15.9	2.5	0.45
1016	13	1	0.45
1017	71	2	0.45
1018	70.9	2	0.45
1019	8.5	2.5	0.45
1020	6.9	1.5	0.45
1021	70.8	2.5	0.45
1022	69.1	2.5	0.45
1023	68.5	2	0.45
1024	10.9	1	0.45
1025	21.5	2.5	0.45
1026	21.4	2	0.45
1027	18.4	2.5	0.45
1028	18.1	2	0.45
1029	12.3	1	0.45
1030	7.8	1.5	0.45
1031	10	1.5	0.45
1032	11.9	1.5	0.45

Reach ID	Bed width (ft)	Initial bed depth (ft)	Porosity
1033	68.1	2	0.45
1034	11.8	1.5	0.45
1035	67.8	2	0.45
1036	65.3	2.5	0.45
1037	65.2	2	0.45
1038	65.2	0.5	0.45
1039	64.9	0.5	0.45
1040	12.7	2	0.45
1041	12.3	1	0.45
1042	25.8	1.5	0.45
1043	22.6	2	0.45
1044	22.3	2.5	0.45
1045	11.3	1.5	0.45
1046	13.2	2	0.45
1047	19.3	2.5	0.45
1048	13.6	1	0.45
1049	15.2	2	0.45
1050	11.9	1	0.45
1051	10	1.5	0.45
1052	64.2	0.5	0.45
1053	64.1	0.5	0.45
1054	63.4	1	0.45
1055	63.2	2	0.45
1056	62.9	1.5	0.45
1057	62.9	2	0.45
1058	58.1	2.5	0.45
1059	58.1	2.5	0.45
1060	58.1	2.5	0.45
1061	58.1	2	0.45
1062	58.1	2.5	0.45
1063	58.1	0.5	0.45
1064	8.1	1	0.45
1065	14.4	1	0.45
1066	31.4	2	0.45
1067	31.4	2	0.45
1068	31.2	2	0.45
1069	29.4	2.5	0.45
1070	28.9	2	0.45
1071	27.8	1.5	0.45
1072	15.8	2	0.45
1073	11	1.5	0.45
1074	11.9	1	0.45
1075	10.5	1.5	0.45
1076	22.7	2	0.45
1077	19.8	2	0.45
1078	14.3	0.5	0.45
1079	13.1	1	0.45
1080	13.9	0.5	0.45
1081	12.4	2	0.45
1082	12.1	1	0.45
1083	4.6	1.5	0.45
1084	1.4	2.5	0.45
1085	1.3	2	0.45

Reach ID	Bed width (ft)	Initial bed depth (ft)	Porosity
1086	57.9	0.5	0.45
1087	57.9	0.5	0.45
1088	57.9	0.5	0.45
1089	57.9	0.5	0.45
1090	11.2	1.5	0.45
1091	4.1	1.5	0.45
1092	57.5	2	0.45
1093	57.4	2.5	0.45
1094	53.7	1	0.45
1095	26.7	2.5	0.45
1096	9.1	1.5	0.45
1097	24.9	2.5	0.45
1098	23.5	1.5	0.45
1099	10	1	0.45
1100	20.7	1.5	0.45
1101	10.1	0.5	0.45
1102	15	1.5	0.45
1103	8.3	2	0.45
1104	7.5	0.5	0.45
1105	11.5	0.5	0.45
1106	4.1	2	0.45
3011	35.1	2.5	0.45
3012	34.9	1.5	0.45
3013	31.5	2.5	0.45
3014	31.5	1.5	0.45
3015	31.3	2	0.45
3016	31	1	0.45
3017	30.9	0.5	0.45
3018	30.6	1	0.45
3019	29	2.5	0.45
3020	29	1	0.45
3021	28.3	1	0.45
3022	27.9	0.5	0.45
3023	27.6	1	0.45
3024	27.3	0.5	0.45
3025	27.3	1	0.45
3026	27.2	1	0.45
3027	20.8	1	0.45
3028	20.2	1	0.45
3029	19	1.5	0.45
3030	15.7	1	0.45
3031	11	0.5	0.45
3032	2.1	1	0.45
3033	5.3	1	0.45
3034	19.1	2.5	0.45
3035	16.6	1.5	0.45
3036	11.1	2	0.45
3037	11.7	2	0.45
3038	9.8	0.5	0.45
3039	11.8	1.5	0.45
3040	7.7	1	0.45
3041	7	1.5	0.45
3042	6.9	1.5	0.45

Reach ID	Bed width (ft)	Initial bed depth (ft)	Porosity
3043	11.2	2.5	0.45
3044	11.1	0.5	0.45
3045	19.4	1.5	0.45
3046	17.7	1	0.45
3047	6.2	1	0.45
3048	5.2	0.5	0.45
3049	15.3	1.5	0.45
3050	14	1	0.45
3051	8.1	0.5	0.45
3052	3.6	1	0.45
3053	12.1	0.5	0.45
3054	10.2	0.5	0.45
30036	11.1	2.5	0.45

Table D-5. Roanoke River watershed model PCB parameters and ranges

Model Parameter	Parameter Description	Value range
POTFW	Washoff potency factor (lb/ton-sediment)	0.00001–0.204
POTFC	Background concentration potency factor (lb/ton-sediment)	0.00001–0.204
ADDC	Atmospheric dry deposition flux (lb/acre/day)	3.91E-08
ADPM1	Partition coefficent with suspended sand (L/mg)	0
ADPM2	Partition coefficent with suspended silt (L/mg)	0.078–0.1139
ADPM3	Partition coefficent with suspended clay (L/mg)	0.078–0.1139
ADPM4	Partition coefficent with bed sand (L/mg)	0
ADPM5	Partition coefficent with bed silt (L/mg)	0.085–5.28
ADPM6	Partition coefficent with bed clay (L/mg)	0.085–5.28
ADPM1	Adorption/desorption rate with suspended sand (L/mg)	2.87
ADPM2	Adorption/desorption rate with suspended silt (L/mg)	2.87
ADPM3	Adorption/desorption rate with suspended clay (L/mg)	2.87
ADPM4	Adorption/desorption rate with bed sand (L/mg)	1.00E-06
ADPM5	Adorption/desorption rate with bed silt (L/mg)	1.00E-06
ADPM6	Adorption/desorption rate with bed clay (L/mg)	1.00E-06

Table D-6. Roanoke River watershed initial streambed sediment PCB concentrations

Reach ID	Total PCBs (mg/mg)
1000	9.77E-09
1001	2.97E-08
1002	2.97E-08
1003	8.57E-08
1004	8.57E-08
1005	8.57E-08
1006	1.89E-07
1007	4.32E-09
1008	4.32E-09
1009	3.82E-09
1010	3.82E-09
1011	3.82E-09
1012	3.82E-09
1013	3.82E-09
1014	3.82E-09
1015	3.82E-09
1016	3.82E-09
1017	1.89E-07

Reach ID	Total PCBs (mg/mg)
1018	8.89E-08
1019	1.86E-08
1020	1.86E-08
1021	8.89E-08
1022	7.06E-09
1023	2.84E-07
1024	9.83E-09
1025	1.91E-09
1026	1.91E-09
1027	6.90E-09
1028	6.90E-09
1029	6.90E-09
1030	6.90E-09
1031	6.90E-09
1032	6.82E-08
1033	2.84E-07
1034	2.20E-09
1035	2.00E-06
1036	2.00E-06
1037	2.00E-06
1038	3.60E-08
1039	3.60E-08
1040	1.86E-08
1041	1.86E-08
1042	6.27E-08
1043	6.27E-08
1044	6.27E-08
1045	6.27E-08
1046	6.27E-08
1047	6.27E-08
1048	6.27E-08
1049	6.27E-08
1050	6.27E-08
1051	4.71E-09
1052	5.65E-09
1053	1.14E-08
1054	6.99E-08
1055	5.24E-08
1056	3.00E-09
1057	2.95E-08
1058	2.95E-08
1059	2.95E-08
1060	8.20E-05
1061	8.20E-05
1062	8.20E-05
1063	8.20E-05
1064	1.86E-08
1065	1.09E-07
1066	2.17E-09
1067	1.46E-09
1068	1.46E-09
1069	1.20E-08
1070	1.20E-08

Reach ID	Total PCBs (mg/mg)
1071	1.20E-08
1072	3.40E-08
1073	3.40E-08
1074	2.37E-08
1075	1.20E-08
1076	3.19E-09
1077	3.19E-09
1078	3.19E-09
1079	3.19E-09
1080	3.19E-09
1081	3.40E-08
1082	3.40E-08
1083	4.28E-08
1084	2.06E-04
1085	2.06E-04
1086	5.98E-07
1087	1.80E-07
1088	8.41E-08
1089	1.95E-09
1090	8.47E-09
1091	5.00E-06
1092	1.96E-08
1093	3.30E-08
1094	3.30E-08
1095	5.34E-09
1096	5.34E-09
1097	5.34E-09
1098	5.34E-09
1099	5.34E-09
1100	5.34E-09
1101	5.34E-09
1102	5.34E-09
1103	5.34E-09
1104	5.34E-09
1105	1.05E-09
1106	1.86E-08
3011	7.18E-07
3012	1.85E-07
3013	3.00E-06
3014	2.00E-06
3015	2.00E-06
3016	3.00E-06
3017	3.00E-06
3018	3.00E-06
3019	7.41E-07
3020	7.41E-07
3021	1.07E-08
3022	1.07E-08
3023	2.54E-08
3024	2.54E-08
3025	1.33E-08
3026	1.33E-08
3027	6.92E-09

Reach ID	Total PCBs (mg/mg)
3028	2.78E-09
3029	3.55E-09
3030	3.55E-09
3031	3.55E-09
3032	1.15E-07
3033	1.86E-08
3034	8.00E-06
3035	8.00E-06
3036	8.00E-06
3037	1.13E-08
3038	1.13E-08
3039	1.13E-08
3040	1.13E-08
3041	2.34E-07
3042	1.26E-07
3043	7.75E-08
3044	7.75E-08
3045	1.11E-08
3046	1.11E-08
3047	1.11E-08
3048	1.11E-08
3049	1.11E-08
3050	1.11E-08
3051	5.11E-08
3052	5.11E-08
3053	3.55E-09
3054	3.55E-09
30036	3.83E-09

Table D-7. Roanoke River watershed baseline and TMDL initial streambed sediment PCB concentrations

Reach ID	Baseline initial total PCBs conc. (mg/mg)	TMDL initial total PCBs conc. (mg/mg)	% Reduction
1000	9.77E-09	9.77E-09	0.000
1001	2.97E-08	1.00E-08	0.664
1002	2.97E-08	1.00E-08	0.664
1003	8.57E-08	1.00E-08	0.883
1004	8.57E-08	1.00E-08	0.883
1005	8.57E-08	1.00E-08	0.883
1006	1.89E-07	1.00E-08	0.947
1007	4.32E-09	4.32E-09	0.000
1008	4.32E-09	4.32E-09	0.000
1009	3.82E-09	3.82E-09	0.000
1010	3.82E-09	3.82E-09	0.000
1011	3.82E-09	3.82E-09	0.000
1012	3.82E-09	3.82E-09	0.000
1013	3.82E-09	3.82E-09	0.000
1014	3.82E-09	3.82E-09	0.000
1015	3.82E-09	3.82E-09	0.000

Reach ID	Baseline initial total PCBs conc. (mg/mg)	TMDL initial total PCBs conc. (mg/mg)	% Reduction
1016	3.82E-09	3.82E-09	0.000
1017	1.89E-07	1.00E-08	0.947
1018	8.89E-08	1.00E-08	0.887
1019	1.86E-08	1.00E-08	0.461
1020	1.86E-08	1.00E-08	0.461
1021	8.89E-08	1.00E-08	0.887
1022	7.06E-09	7.06E-09	0.000
1023	2.84E-07	1.00E-08	0.965
1024	9.83E-09	9.83E-09	0.000
1025	1.91E-09	1.91E-09	0.000
1026	1.91E-09	1.91E-09	0.000
1027	6.90E-09	6.90E-09	0.000
1028	6.90E-09	6.90E-09	0.000
1029	6.90E-09	6.90E-09	0.000
1030	6.90E-09	6.90E-09	0.000
1031	6.90E-09	6.90E-09	0.000
1032	6.82E-08	1.00E-08	0.853
1033	2.84E-07	1.00E-08	0.965
1034	2.20E-09	2.20E-09	0.000
1035	2.00E-06	1.00E-08	0.995
1036	2.00E-06	1.00E-08	0.995
1037	2.00E-06	1.00E-08	0.995
1038	3.60E-08	1.00E-08	0.722
1039	3.60E-08	1.00E-08	0.722
1040	1.86E-08	1.00E-08	0.461
1041	1.86E-08	1.00E-08	0.461
1042	6.27E-08	1.00E-08	0.840
1043	6.27E-08	1.00E-08	0.840
1044	6.27E-08	1.00E-08	0.840
1045	6.27E-08	1.00E-08	0.840
1046	6.27E-08	1.00E-08	0.840
1047	6.27E-08	1.00E-08	0.840
1048	6.27E-08	1.00E-08	0.840
1049	6.27E-08	1.00E-08	0.840
1050	6.27E-08	1.00E-08	0.840
1051	4.71E-09	4.71E-09	0.000
1052	5.65E-09	5.65E-09	0.000
1053	1.14E-08	1.00E-08	0.123
1054	6.99E-08	1.00E-08	0.857
1055	5.24E-08	1.00E-08	0.809
1056	3.00E-09	3.00E-09	0.000
1057	2.95E-08	1.00E-08	0.661
1058	2.95E-08	1.00E-08	0.661
1059	2.95E-08	1.00E-08	0.661
1060	8.20E-05	1.00E-08	1.000
1061	8.20E-05	1.00E-08	1.000
1062	8.20E-05	1.00E-08	1.000

Reach ID	Baseline initial total PCBs conc. (mg/mg)	TMDL initial total PCBs conc. (mg/mg)	% Reduction
1063	8.20E-05	1.00E-08	1.000
1064	1.86E-08	1.00E-08	0.461
1065	1.09E-07	1.00E-08	0.909
1066	2.17E-09	2.17E-09	0.000
1067	1.46E-09	1.46E-09	0.000
1068	1.46E-09	1.46E-09	0.000
1069	1.20E-08	1.00E-08	0.167
1070	1.20E-08	1.00E-08	0.167
1071	1.20E-08	1.00E-08	0.167
1072	3.40E-08	1.00E-08	0.706
1073	3.40E-08	1.00E-08	0.706
1074	2.37E-08	1.00E-08	0.578
1075	1.20E-08	1.00E-08	0.167
1076	3.19E-09	3.19E-09	0.000
1077	3.19E-09	3.19E-09	0.000
1078	3.19E-09	3.19E-09	0.000
1079	3.19E-09	3.19E-09	0.000
1080	3.19E-09	3.19E-09	0.000
1081	3.40E-08	1.00E-08	0.706
1082	3.40E-08	1.00E-08	0.706
1083	4.28E-08	1.00E-08	0.766
1084	2.06E-04	1.00E-08	1.000
1085	2.06E-04	1.00E-08	1.000
1086	5.98E-07	1.00E-08	0.983
1087	1.80E-07	1.00E-08	0.944
1088	8.41E-08	1.00E-08	0.881
1089	1.95E-09	1.95E-09	0.000
1090	8.47E-09	8.47E-09	0.000
1091	5.00E-06	1.00E-08	0.998
1092	1.96E-08	1.00E-08	0.489
1093	3.30E-08	1.00E-08	0.697
1094	3.30E-08	1.00E-08	0.697
1095	5.34E-09	5.34E-09	0.000
1096	5.34E-09	5.34E-09	0.000
1097	5.34E-09	5.34E-09	0.000
1098	5.34E-09	5.34E-09	0.000
1099	5.34E-09	5.34E-09	0.000
1100	5.34E-09	5.34E-09	0.000
1101	5.34E-09	5.34E-09	0.000
1102	5.34E-09	5.34E-09	0.000
1103	5.34E-09	5.34E-09	0.000
1104	5.34E-09	5.34E-09	0.000
1105	1.05E-09	1.05E-09	0.000
1106	1.86E-08	1.00E-08	0.461
3011	7.18E-07	1.50E-08	0.979
3012	1.85E-07	1.50E-08	0.919
3013	3.00E-06	1.50E-08	0.995

Reach ID	Baseline initial total PCBs conc. (mg/mg)	TMDL initial total PCBs conc. (mg/mg)	% Reduction
3014	2.00E-06	1.50E-08	0.993
3015	2.00E-06	1.50E-08	0.993
3016	3.00E-06	1.50E-08	0.995
3017	3.00E-06	1.50E-08	0.995
3018	3.00E-06	1.50E-08	0.995
3019	7.41E-07	1.50E-08	0.980
3020	7.41E-07	1.50E-08	0.980
3021	1.07E-08	1.07E-08	0.000
3022	1.07E-08	1.07E-08	0.000
3023	2.54E-08	1.50E-08	0.410
3024	2.54E-08	1.50E-08	0.410
3025	1.33E-08	1.33E-08	0.000
3026	1.33E-08	1.33E-08	0.000
3027	6.92E-09	6.92E-09	0.000
3028	2.78E-09	2.78E-09	0.000
3029	3.55E-09	3.55E-09	0.000
3030	3.55E-09	3.55E-09	0.000
3031	3.55E-09	3.55E-09	0.000
3032	1.15E-07	1.50E-08	0.870
3033	1.86E-08	1.50E-08	0.192
3034	8.00E-06	1.50E-08	0.998
3035	8.00E-06	1.50E-08	0.998
3036	8.00E-06	1.50E-08	0.998
3037	1.13E-08	1.13E-08	0.000
3038	1.13E-08	1.13E-08	0.000
3039	1.13E-08	1.13E-08	0.000
3040	1.13E-08	1.13E-08	0.000
3041	2.34E-07	1.50E-08	0.936
3042	1.26E-07	1.50E-08	0.881
3043	7.75E-08	1.50E-08	0.807
3044	7.75E-08	1.50E-08	0.807
3045	1.11E-08	1.11E-08	0.000
3046	1.11E-08	1.11E-08	0.000
3047	1.11E-08	1.11E-08	0.000
3048	1.11E-08	1.11E-08	0.000
3049	1.11E-08	1.11E-08	0.000
3050	1.11E-08	1.11E-08	0.000
3051	5.11E-08	1.50E-08	0.706
3052	5.11E-08	1.50E-08	0.706
3053	3.55E-09	3.55E-09	0.000
3054	3.55E-09	3.55E-09	0.000
30036	3.83E-09	3.83E-09	0.000

Table D-8. Stream and river segments associated with model subbasins

Watershed Section	Model subbasin	Stream name
Upper	3043	Masons Creek

Watershed Section	Model subbasin	Stream name
Upper	3044	Masons Creek
Upper	3045	North Fork Roanoke River
Upper	3046	North Fork Roanoke River
Upper	3047	North Fork Roanoke River
Upper	3048	North Fork Roanoke River
Upper	3049	North Fork Roanoke River
Upper	3050	North Fork Roanoke River
Upper	3051	North Fork Roanoke River
Upper	3052	North Fork Roanoke River
Upper	3041	Peters Creek
Upper	3042	Peters Creek
Upper	3010	Roanoke River
Upper	3011	Roanoke River
Upper	3012	Roanoke River
Upper	3013	Roanoke River
Upper	3014	Roanoke River
Upper	3015	Roanoke River
Upper	3016	Roanoke River
Upper	3017	Roanoke River
Upper	3018	Roanoke River
Upper	3019	Roanoke River
Upper	3020	Roanoke River
Upper	3021	Roanoke River
Upper	3022	Roanoke River
Upper	3023	Roanoke River
Upper	3024	Roanoke River
Upper	3025	Roanoke River
Upper	3026	Roanoke River
Upper	3027	South Fork Roanoke River
Upper	3028	South Fork Roanoke River
Upper	3029	South Fork Roanoke River
Upper	3030	South Fork Roanoke River
Upper	3031	South Fork Roanoke River
Upper	3053	South Fork Roanoke River
Upper	3054	South Fork Roanoke River
Upper	3034	Tinker Creek
Upper	3035	Tinker Creek
Upper	3036	Tinker Creek
Upper	3037	Tinker Creek
Upper	3038	Tinker Creek
Upper	3039	Tinker Creek
Upper	3040	Tinker Creek
Upper	30036	Tinker Creek
Upper	3032	Unnamed Trib to Roanoke River
Upper	3033	Wolf Creek
Lower	1066	Big Otter River
Lower	1067	Big Otter River
Lower	1068	Big Otter River
Lower	1069	Big Otter River
Lower	1070	Big Otter River
Lower	1071	Big Otter River

Watershed Section	Model subbasin	Stream name
Lower	1074	Big Otter River
Lower	1075	Big Otter River
Lower	1076	Big Otter River
Lower	1077	Big Otter River
Lower	1078	Big Otter River
Lower	1079	Big Otter River
Lower	1080	Big Otter River
Lower	1007	Black Walnut Creek
Lower	1008	Black Walnut Creek
Lower	1024	Catawba Creek
Lower	1034	Childrey Creek
Lower	1025	Cub Creek
Lower	1026	Cub Creek
Lower	1027	Cub Creek
Lower	1028	Cub Creek
Lower	1029	Cub Creek
Lower	1030	Cub Creek
Lower	1031	Cub Creek
Lower	1001	Difficult Creek
Lower	1002	Difficult Creek
Lower	1042	Falling River
Lower	1043	Falling River
Lower	1044	Falling River
Lower	1045	Falling River
Lower	1046	Falling River
Lower	1047	Falling River
Lower	1048	Falling River
Lower	1049	Falling River
Lower	1050	Falling River
Lower	1095	Goose Creek
Lower	1096	Goose Creek
Lower	1097	Goose Creek
Lower	1098	Goose Creek
Lower	1099	Goose Creek
Lower	1100	Goose Creek
Lower	1101	Goose Creek
Lower	1102	Goose Creek
Lower	1103	Goose Creek
Lower	1104	Goose Creek
Lower	1105	Goose Creek
Lower	1019	Hunting Creek
Lower	1020	Hunting Creek
Lower	1072	Little Otter River
Lower	1073	Little Otter River
Lower	1081	Little Otter River
Lower	1082	Little Otter River
Lower	1091	Lynch Creek
Lower	1064	Reed Creek
Lower	1009	Roanoke Creek
Lower	1010	Roanoke Creek
Lower	1011	Roanoke Creek
Lower	1012	Roanoke Creek

Watershed Section	Model subbasin	Stream name
Lower	1013	Roanoke Creek
Lower	1014	Roanoke Creek
Lower	1015	Roanoke Creek
Lower	1016	Roanoke Creek
Lower	1000	Roanoke River
Lower	1003	Roanoke River
Lower	1004	Roanoke River
Lower	1005	Roanoke River
Lower	1006	Roanoke River
Lower	1017	Roanoke River
Lower	1018	Roanoke River
Lower	1021	Roanoke River
Lower	1022	Roanoke River
Lower	1023	Roanoke River
Lower	1033	Roanoke River
Lower	1035	Roanoke River
Lower	1036	Roanoke River
Lower	1037	Roanoke River
Lower	1038	Roanoke River
Lower	1039	Roanoke River
Lower	1052	Roanoke River
Lower	1053	Roanoke River
Lower	1054	Roanoke River
Lower	1055	Roanoke River
Lower	1056	Roanoke River
Lower	1057	Roanoke River
Lower	1058	Roanoke River
Lower	1059	Roanoke River
Lower	1060	Roanoke River
Lower	1061	Roanoke River
Lower	1062	Roanoke River
Lower	1063	Roanoke River
Lower	1086	Roanoke River
Lower	1087	Roanoke River
Lower	1088	Roanoke River
Lower	1089	Roanoke River
Lower	1092	Roanoke River
Lower	1093	Roanoke River
Lower	1094	Roanoke River
Lower	1065	Seneca Creek
Lower	1040	Straightstone Creek
Lower	1041	Straightstone Creek
Lower	1106	Straightstone Creek
Lower	1090	Sycamore Creek
Lower	1032	Turnip Creek
Lower	1083	Unnamed Trib to Roanoke River
Lower	1051	Whipping Creek
Lower	1084	X-trib
Lower	1085	X-trib

Table D-9. Leesville Dam average daily discharge time series

Date	Flow (cfs)
1/1/90	7220
1/2/90	7120
1/3/90	2990
1/4/90	1400
1/5/90	992
1/6/90	1210
1/7/90	1600
1/8/90	2080
1/9/90	3540
1/10/90	3810
1/11/90	2300
1/12/90	1660
1/13/90	1220
1/14/90	1200
1/15/90	941
1/16/90	684
1/17/90	708
1/18/90	872
1/19/90	945
1/20/90	1010
1/21/90	966
1/22/90	1030
1/23/90	1080
1/24/90	1010
1/25/90	1490
1/26/90	2310
1/27/90	2170
1/28/90	1810
1/29/90	1210
1/30/90	1140
1/31/90	2460
2/1/90	1820
2/2/90	1470
2/3/90	1290
2/4/90	1710
2/5/90	3370
2/6/90	1980
2/7/90	1460
2/8/90	1410
2/9/90	1300
2/10/90	2250
2/11/90	4490
2/12/90	1960
2/13/90	1980
2/14/90	1460
2/15/90	1460
2/16/90	2410

Date	Flow (cfs)
2/17/90	2580
2/18/90	1440
2/19/90	807
2/20/90	1310
2/21/90	1910
2/22/90	1940
2/23/90	2160
2/24/90	2270
2/25/90	1850
2/26/90	285
2/27/90	363
2/28/90	664
3/1/90	1170
3/2/90	1370
3/3/90	1240
3/4/90	2130
3/5/90	1520
3/6/90	1030
3/7/90	884
3/8/90	857
3/9/90	896
3/10/90	1020
3/11/90	975
3/12/90	982
3/13/90	1080
3/14/90	1010
3/15/90	985
3/16/90	2700
3/17/90	4150
3/18/90	6240
3/19/90	5460
3/20/90	977
3/21/90	565
3/22/90	748
3/23/90	898
3/24/90	1210
3/25/90	1220
3/26/90	1310
3/27/90	1250
3/28/90	1290
3/29/90	1490
3/30/90	1940
3/31/90	2800
4/1/90	2840
4/2/90	3560
4/3/90	4310
4/4/90	2170

Date	Flow (cfs)
4/5/90	1490
4/6/90	1230
4/7/90	2910
4/8/90	2850
4/9/90	2340
4/10/90	1760
4/11/90	1600
4/12/90	1670
4/13/90	1510
4/14/90	1550
4/15/90	2120
4/16/90	3160
4/17/90	1400
4/18/90	1100
4/19/90	1170
4/20/90	1180
4/21/90	1140
4/22/90	1010
4/23/90	1180
4/24/90	1410
4/25/90	1260
4/26/90	1100
4/27/90	1090
4/28/90	1090
4/29/90	1010
4/30/90	934
5/1/90	1050
5/2/90	1120
5/3/90	1160
5/4/90	1140
5/5/90	1210
5/6/90	1520
5/7/90	1210
5/8/90	1140
5/9/90	1000
5/10/90	639
5/11/90	3610
5/12/90	1480
5/13/90	955
5/14/90	967
5/15/90	990
5/16/90	914
5/17/90	806
5/18/90	846
5/19/90	850
5/20/90	803
5/21/90	795

Date	Flow (cfs)
5/22/90	2720
5/23/90	3980
5/24/90	1710
5/25/90	1360
5/26/90	1260
5/27/90	1140
5/28/90	5550
5/29/90	7060
5/30/90	7490
5/31/90	2370
6/1/90	1400
6/2/90	1210
6/3/90	1300
6/4/90	1220
6/5/90	1080
6/6/90	808
6/7/90	648
6/8/90	558
6/9/90	432
6/10/90	436
6/11/90	1110
6/12/90	1080
6/13/90	861
6/14/90	704
6/15/90	680
6/16/90	609
6/17/90	622
6/18/90	665
6/19/90	558
6/20/90	615
6/21/90	606
6/22/90	539
6/23/90	491
6/24/90	636
6/25/90	468
6/26/90	839
6/27/90	919
6/28/90	375
6/29/90	659
6/30/90	685
7/1/90	683
7/2/90	677
7/3/90	595
7/4/90	593
7/5/90	589
7/6/90	575
7/7/90	582

Date	Flow (cfs)
7/8/90	575
7/9/90	563
7/10/90	617
7/11/90	568
7/12/90	399
7/13/90	447
7/14/90	6710
7/15/90	4980
7/16/90	8500
7/17/90	3150
7/18/90	440
7/19/90	851
7/20/90	950
7/21/90	812
7/22/90	687
7/23/90	547
7/24/90	663
7/25/90	652
7/26/90	493
7/27/90	454
7/28/90	465
7/29/90	457
7/30/90	448
7/31/90	456
8/1/90	476
8/2/90	480
8/3/90	437
8/4/90	421
8/5/90	396
8/6/90	1760
8/7/90	1640
8/8/90	778
8/9/90	740
8/10/90	622
8/11/90	493
8/12/90	485
8/13/90	511
8/14/90	539
8/15/90	410
8/16/90	453
8/17/90	308
8/18/90	519
8/19/90	539
8/20/90	512
8/21/90	1740
8/22/90	1350
8/23/90	426

Date	Flow (cfs)
8/24/90	593
8/25/90	1150
8/26/90	1200
8/27/90	897
8/28/90	558
8/29/90	539
8/30/90	524
8/31/90	530
9/1/90	543
9/2/90	551
9/3/90	547
9/4/90	543
9/5/90	538
9/6/90	524
9/7/90	513
9/8/90	530
9/9/90	504
9/10/90	461
9/11/90	497
9/12/90	506
9/13/90	503
9/14/90	103
9/15/90	458
9/16/90	482
9/17/90	534
9/18/90	568
9/19/90	518
9/20/90	508
9/21/90	706
9/22/90	890
9/23/90	508
9/24/90	518
9/25/90	527
9/26/90	528
9/27/90	534
9/28/90	574
9/29/90	575
9/30/90	558
10/1/90	553
10/2/90	503
10/3/90	458
10/4/90	519
10/5/90	568
10/6/90	596
10/7/90	605
10/8/90	502
10/9/90	696

Date	Flow (cfs)
10/10/90	609
10/11/90	4390
10/12/90	6640
10/13/90	4670
10/14/90	7770
10/15/90	2360
10/16/90	688
10/17/90	334
10/18/90	791
10/19/90	3590
10/20/90	3510
10/21/90	1400
10/22/90	0
10/23/90	3410
10/24/90	14700
10/25/90	10200
10/26/90	3470
10/27/90	3730
10/28/90	3580
10/29/90	969
10/30/90	551
10/31/90	501
11/1/90	611
11/2/90	612
11/3/90	567
11/4/90	596
11/5/90	753
11/6/90	874
11/7/90	972
11/8/90	805
11/9/90	1590
11/10/90	2750
11/11/90	1640
11/12/90	612
11/13/90	372
11/14/90	351
11/15/90	437
11/16/90	540
11/17/90	689
11/18/90	721
11/19/90	720
11/20/90	738
11/21/90	721
11/22/90	670
11/23/90	667
11/24/90	680
11/25/90	693

Date	Flow (cfs)
11/26/90	630
11/27/90	514
11/28/90	547
11/29/90	557
11/30/90	649
12/1/90	661
12/2/90	659
12/3/90	497
12/4/90	2000
12/5/90	3620
12/6/90	1240
12/7/90	760
12/8/90	808
12/9/90	837
12/10/90	824
12/11/90	845
12/12/90	871
12/13/90	821
12/14/90	753
12/15/90	737
12/16/90	742
12/17/90	764
12/18/90	781
12/19/90	781
12/20/90	867
12/21/90	806
12/22/90	798
12/23/90	856
12/24/90	2610
12/25/90	3900
12/26/90	1980
12/27/90	1420
12/28/90	855
12/29/90	2400
12/30/90	3350
12/31/90	2490
1/1/91	2900
1/2/91	1630
1/3/91	1360
1/4/91	1040
1/5/91	851
1/6/91	842
1/7/91	1060
1/8/91	1460
1/9/91	1520
1/10/91	2540
1/11/91	3510

Date	Flow (cfs)
1/12/91	6660
1/13/91	8210
1/14/91	8420
1/15/91	4320
1/16/91	3330
1/17/91	3620
1/18/91	2470
1/19/91	1850
1/20/91	1090
1/21/91	1420
1/22/91	1760
1/23/91	1480
1/24/91	1010
1/25/91	995
1/26/91	1010
1/27/91	1010
1/28/91	1000
1/29/91	1020
1/30/91	1210
1/31/91	1320
2/1/91	1070
2/2/91	816
2/3/91	807
2/4/91	729
2/5/91	735
2/6/91	944
2/7/91	1130
2/8/91	882
2/9/91	1240
2/10/91	1270
2/11/91	1170
2/12/91	735
2/13/91	697
2/14/91	852
2/15/91	886
2/16/91	918
2/17/91	872
2/18/91	827
2/19/91	3670
2/20/91	3460
2/21/91	2140
2/22/91	851
2/23/91	1060
2/24/91	1060
2/25/91	1060
2/26/91	1130
2/27/91	1260

Date	Flow (cfs)
2/28/91	1290
3/1/91	1400
3/2/91	1520
3/3/91	3710
3/4/91	5350
3/5/91	8130
3/6/91	8370
3/7/91	5430
3/8/91	1700
3/9/91	1340
3/10/91	1410
3/11/91	1280
3/12/91	961
3/13/91	1350
3/14/91	1540
3/15/91	1730
3/16/91	1920
3/17/91	1990
3/18/91	1870
3/19/91	2020
3/20/91	2130
3/21/91	1710
3/22/91	1630
3/23/91	1820
3/24/91	1780
3/25/91	1990
3/26/91	2060
3/27/91	2250
3/28/91	2890
3/29/91	3820
3/30/91	5600
3/31/91	7940
4/1/91	8100
4/2/91	3390
4/3/91	2030
4/4/91	1560
4/5/91	1390
4/6/91	1420
4/7/91	1460
4/8/91	1490
4/9/91	1620
4/10/91	2290
4/11/91	2090
4/12/91	1680
4/13/91	1260
4/14/91	1320
4/15/91	1930

Date	Flow (cfs)
4/16/91	2210
4/17/91	2200
4/18/91	1700
4/19/91	1670
4/20/91	1960
4/21/91	1970
4/22/91	1550
4/23/91	1500
4/24/91	1400
4/25/91	1260
4/26/91	1200
4/27/91	1190
4/28/91	1150
4/29/91	1210
4/30/91	1390
5/1/91	1710
5/2/91	1550
5/3/91	1260
5/4/91	1200
5/5/91	1020
5/6/91	880
5/7/91	886
5/8/91	1110
5/9/91	1150
5/10/91	1130
5/11/91	921
5/12/91	907
5/13/91	973
5/14/91	995
5/15/91	1080
5/16/91	1200
5/17/91	993
5/18/91	994
5/19/91	1180
5/20/91	2390
5/21/91	3800
5/22/91	3120
5/23/91	1710
5/24/91	1170
5/25/91	1040
5/26/91	1000
5/27/91	911
5/28/91	597
5/29/91	1710
5/30/91	1010
5/31/91	802
6/1/91	698

Date	Flow (cfs)
6/2/91	534
6/3/91	645
6/4/91	988
6/5/91	929
6/6/91	861
6/7/91	696
6/8/91	633
6/9/91	634
6/10/91	603
6/11/91	571
6/12/91	566
6/13/91	572
6/14/91	572
6/15/91	488
6/16/91	475
6/17/91	455
6/18/91	476
6/19/91	1890
6/20/91	1880
6/21/91	909
6/22/91	669
6/23/91	724
6/24/91	654
6/25/91	554
6/26/91	512
6/27/91	516
6/28/91	522
6/29/91	539
6/30/91	522
7/1/91	519
7/2/91	556
7/3/91	631
7/4/91	452
7/5/91	1530
7/6/91	1310
7/7/91	1300
7/8/91	1260
7/9/91	979
7/10/91	721
7/11/91	583
7/12/91	443
7/13/91	507
7/14/91	579
7/15/91	603
7/16/91	571
7/17/91	577
7/18/91	585

Date	Flow (cfs)
7/19/91	591
7/20/91	552
7/21/91	577
7/22/91	583
7/23/91	578
7/24/91	587
7/25/91	420
7/26/91	627
7/27/91	587
7/28/91	1030
7/29/91	1710
7/30/91	2350
7/31/91	1750
8/1/91	695
8/2/91	565
8/3/91	585
8/4/91	591
8/5/91	589
8/6/91	620
8/7/91	656
8/8/91	612
8/9/91	569
8/10/91	551
8/11/91	567
8/12/91	604
8/13/91	611
8/14/91	598
8/15/91	572
8/16/91	609
8/17/91	607
8/18/91	597
8/19/91	600
8/20/91	618
8/21/91	584
8/22/91	614
8/23/91	622
8/24/91	625
8/25/91	629
8/26/91	625
8/27/91	620
8/28/91	548
8/29/91	560
8/30/91	605
8/31/91	621
9/1/91	606
9/2/91	584
9/3/91	611

Date	Flow (cfs)
9/4/91	615
9/5/91	617
9/6/91	601
9/7/91	605
9/8/91	614
9/9/91	611
9/10/91	637
9/11/91	892
9/12/91	663
9/13/91	633
9/14/91	626
9/15/91	625
9/16/91	613
9/17/91	642
9/18/91	643
9/19/91	628
9/20/91	635
9/21/91	657
9/22/91	682
9/23/91	639
9/24/91	651
9/25/91	621
9/26/91	916
9/27/91	586
9/28/91	605
9/29/91	600
9/30/91	635
10/1/91	570
10/2/91	475
10/3/91	477
10/4/91	734
10/5/91	1120
10/6/91	480
10/7/91	574
10/8/91	620
10/9/91	618
10/10/91	608
10/11/91	619
10/12/91	642
10/13/91	628
10/14/91	610
10/15/91	619
10/16/91	603
10/17/91	609
10/18/91	624
10/19/91	627
10/20/91	627

Date	Flow (cfs)
10/21/91	616
10/22/91	607
10/23/91	590
10/24/91	593
10/25/91	595
10/26/91	604
10/27/91	624
10/28/91	612
10/29/91	616
10/30/91	574
10/31/91	577
11/1/91	612
11/2/91	652
11/3/91	632
11/4/91	599
11/5/91	635
11/6/91	607
11/7/91	607
11/8/91	596
11/9/91	606
11/10/91	554
11/11/91	335
11/12/91	529
11/13/91	584
11/14/91	592
11/15/91	609
11/16/91	602
11/17/91	588
11/18/91	622
11/19/91	619
11/20/91	606
11/21/91	620
11/22/91	505
11/23/91	469
11/24/91	593
11/25/91	638
11/26/91	618
11/27/91	580
11/28/91	568
11/29/91	574
11/30/91	597
12/1/91	554
12/2/91	429
12/3/91	373
12/4/91	83.2
12/5/91	420
12/6/91	487

Date	Flow (cfs)
12/7/91	523
12/8/91	504
12/9/91	511
12/10/91	528
12/11/91	517
12/12/91	528
12/13/91	531
12/14/91	525
12/15/91	587
12/16/91	516
12/17/91	557
12/18/91	541
12/19/91	546
12/20/91	541
12/21/91	545
12/22/91	554
12/23/91	575
12/24/91	558
12/25/91	549
12/26/91	538
12/27/91	556
12/28/91	571
12/29/91	396
12/30/91	440
12/31/91	452
1/1/92	468
1/2/92	483
1/3/92	0
1/4/92	881
1/5/92	4550
1/6/92	2410
1/7/92	1370
1/8/92	1280
1/9/92	1150
1/10/92	1080
1/11/92	840
1/12/92	851
1/13/92	848
1/14/92	666
1/15/92	722
1/16/92	685
1/17/92	598
1/18/92	548
1/19/92	542
1/20/92	497
1/21/92	492
1/22/92	500

Date	Flow (cfs)
1/23/92	458
1/24/92	400
1/25/92	726
1/26/92	769
1/27/92	709
1/28/92	545
1/29/92	507
1/30/92	493
1/31/92	493
2/1/92	501
2/2/92	508
2/3/92	506
2/4/92	510
2/5/92	515
2/6/92	521
2/7/92	515
2/8/92	489
2/9/92	510
2/10/92	523
2/11/92	506
2/12/92	509
2/13/92	549
2/14/92	550
2/15/92	523
2/16/92	428
2/17/92	494
2/18/92	633
2/19/92	897
2/20/92	885
2/21/92	781
2/22/92	640
2/23/92	643
2/24/92	731
2/25/92	1800
2/26/92	5740
2/27/92	8530
2/28/92	3810
2/29/92	1930
3/1/92	1640
3/2/92	861
3/3/92	305
3/4/92	847
3/5/92	837
3/6/92	831
3/7/92	1520
3/8/92	3870
3/9/92	2300

Date	Flow (cfs)
3/10/92	1860
3/11/92	2880
3/12/92	2700
3/13/92	1510
3/14/92	816
3/15/92	849
3/16/92	848
3/17/92	867
3/18/92	866
3/19/92	861
3/20/92	873
3/21/92	888
3/22/92	899
3/23/92	879
3/24/92	811
3/25/92	636
3/26/92	622
3/27/92	1100
3/28/92	1380
3/29/92	1400
3/30/92	1410
3/31/92	1130
4/1/92	777
4/2/92	692
4/3/92	686
4/4/92	638
4/5/92	608
4/6/92	647
4/7/92	768
4/8/92	748
4/9/92	638
4/10/92	644
4/11/92	653
4/12/92	654
4/13/92	626
4/14/92	564
4/15/92	531
4/16/92	522
4/17/92	533
4/18/92	464
4/19/92	783
4/20/92	1410
4/21/92	2800
4/22/92	9660
4/23/92	13900
4/24/92	13800
4/25/92	9070

Date	Flow (cfs)
4/26/92	8660
4/27/92	6510
4/28/92	1620
4/29/92	2600
4/30/92	1700
5/1/92	1420
5/2/92	1310
5/3/92	1330
5/4/92	1320
5/5/92	1060
5/6/92	570
5/7/92	1280
5/8/92	4280
5/9/92	2840
5/10/92	1420
5/11/92	1930
5/12/92	1400
5/13/92	1070
5/14/92	1010
5/15/92	5100
5/16/92	3920
5/17/92	5760
5/18/92	1530
5/19/92	2590
5/20/92	2360
5/21/92	1900
5/22/92	1510
5/23/92	1280
5/24/92	1300
5/25/92	1300
5/26/92	1220
5/27/92	876
5/28/92	754
5/29/92	1060
5/30/92	1370
5/31/92	1380
6/1/92	1430
6/2/92	1170
6/3/92	1060
6/4/92	3000
6/5/92	6250
6/6/92	8140
6/7/92	8670
6/8/92	6350
6/9/92	7070
6/10/92	2820
6/11/92	2440

Date	Flow (cfs)
6/12/92	1960
6/13/92	1820
6/14/92	1220
6/15/92	1030
6/16/92	1500
6/17/92	1790
6/18/92	1190
6/19/92	1000
6/20/92	967
6/21/92	986
6/22/92	1000
6/23/92	945
6/24/92	804
6/25/92	707
6/26/92	598
6/27/92	676
6/28/92	491
6/29/92	675
6/30/92	870
7/1/92	809
7/2/92	818
7/3/92	859
7/4/92	838
7/5/92	878
7/6/92	893
7/7/92	922
7/8/92	880
7/9/92	694
7/10/92	613
7/11/92	573
7/12/92	525
7/13/92	554
7/14/92	617
7/15/92	617
7/16/92	561
7/17/92	552
7/18/92	545
7/19/92	560
7/20/92	542
7/21/92	546
7/22/92	543
7/23/92	210
7/24/92	81.9
7/25/92	0
7/26/92	820
7/27/92	1280
7/28/92	1670

Date	Flow (cfs)
7/29/92	1560
7/30/92	1070
7/31/92	905
8/1/92	549
8/2/92	564
8/3/92	572
8/4/92	553
8/5/92	580
8/6/92	565
8/7/92	532
8/8/92	493
8/9/92	493
8/10/92	505
8/11/92	519
8/12/92	546
8/13/92	546
8/14/92	361
8/15/92	516
8/16/92	548
8/17/92	551
8/18/92	560
8/19/92	492
8/20/92	489
8/21/92	515
8/22/92	523
8/23/92	526
8/24/92	534
8/25/92	540
8/26/92	543
8/27/92	663
8/28/92	2590
8/29/92	311
8/30/92	498
8/31/92	518
9/1/92	543
9/2/92	598
9/3/92	622
9/4/92	595
9/5/92	315
9/6/92	187
9/7/92	186
9/8/92	549
9/9/92	516
9/10/92	541
9/11/92	517
9/12/92	536
9/13/92	543

Date	Flow (cfs)
9/14/92	555
9/15/92	558
9/16/92	568
9/17/92	580
9/18/92	593
9/19/92	595
9/20/92	549
9/21/92	544
9/22/92	531
9/23/92	542
9/24/92	619
9/25/92	554
9/26/92	483
9/27/92	539
9/28/92	475
9/29/92	453
9/30/92	553
10/1/92	557
10/2/92	565
10/3/92	588
10/4/92	553
10/5/92	259
10/6/92	446
10/7/92	518
10/8/92	533
10/9/92	448
10/10/92	335
10/11/92	482
10/12/92	515
10/13/92	545
10/14/92	547
10/15/92	552
10/16/92	542
10/17/92	572
10/18/92	583
10/19/92	577
10/20/92	569
10/21/92	561
10/22/92	566
10/23/92	563
10/24/92	559
10/25/92	555
10/26/92	538
10/27/92	551
10/28/92	562
10/29/92	563
10/30/92	545

Date	Flow (cfs)
10/31/92	463
11/1/92	435
11/2/92	516
11/3/92	272
11/4/92	399
11/5/92	186
11/6/92	371
11/7/92	462
11/8/92	380
11/9/92	461
11/10/92	521
11/11/92	516
11/12/92	337
11/13/92	0
11/14/92	1960
11/15/92	1290
11/16/92	530
11/17/92	541
11/18/92	448
11/19/92	430
11/20/92	451
11/21/92	439
11/22/92	370
11/23/92	1820
11/24/92	2360
11/25/92	1490
11/26/92	3400
11/27/92	2730
11/28/92	1640
11/29/92	683
11/30/92	426
12/1/92	665
12/2/92	611
12/3/92	589
12/4/92	579
12/5/92	568
12/6/92	577
12/7/92	522
12/8/92	542
12/9/92	607
12/10/92	676
12/11/92	1100
12/12/92	1400
12/13/92	1440
12/14/92	1200
12/15/92	849
12/16/92	1120

Date	Flow (cfs)
12/17/92	1930
12/18/92	2520
12/19/92	2050
12/20/92	1600
12/21/92	1350
12/22/92	1100
12/23/92	811
12/24/92	912
12/25/92	801
12/26/92	569
12/27/92	507
12/28/92	825
12/29/92	938
12/30/92	1910
12/31/92	1300
1/1/93	1120
1/2/93	972
1/3/93	609
1/4/93	499
1/5/93	1440
1/6/93	3840
1/7/93	1980
1/8/93	1540
1/9/93	4170
1/10/93	7320
1/11/93	2890
1/12/93	2770
1/13/93	2670
1/14/93	2240
1/15/93	1630
1/16/93	1300
1/17/93	1320
1/18/93	1200
1/19/93	1020
1/20/93	918
1/21/93	1300
1/22/93	1650
1/23/93	1760
1/24/93	1330
1/25/93	1700
1/26/93	2010
1/27/93	1420
1/28/93	1460
1/29/93	1400
1/30/93	1230
1/31/93	1120
2/1/93	768

Date	Flow (cfs)
2/2/93	710
2/3/93	575
2/4/93	623
2/5/93	753
2/6/93	737
2/7/93	745
2/8/93	801
2/9/93	857
2/10/93	935
2/11/93	896
2/12/93	1430
2/13/93	2170
2/14/93	2080
2/15/93	884
2/16/93	866
2/17/93	1560
2/18/93	2310
2/19/93	1380
2/20/93	1200
2/21/93	1700
2/22/93	3380
2/23/93	4130
2/24/93	4220
2/25/93	4230
2/26/93	2020
2/27/93	1500
2/28/93	1300
3/1/93	1150
3/2/93	1810
3/3/93	2450
3/4/93	2560
3/5/93	11100
3/6/93	14900
3/7/93	11600
3/8/93	3930
3/9/93	3970
3/10/93	2880
3/11/93	1980
3/12/93	2260
3/13/93	3250
3/14/93	3620
3/15/93	1010
3/16/93	2540
3/17/93	2260
3/18/93	2870
3/19/93	3990
3/20/93	4530

Date	Flow (cfs)
3/21/93	4350
3/22/93	5300
3/23/93	7120
3/24/93	3810
3/25/93	9370
3/26/93	12000
3/27/93	9040
3/28/93	8720
3/29/93	8960
3/30/93	5920
3/31/93	5080
4/1/93	2910
4/2/93	2140
4/3/93	2120
4/4/93	1840
4/5/93	1960
4/6/93	2500
4/7/93	2700
4/8/93	3920
4/9/93	2680
4/10/93	2210
4/11/93	3470
4/12/93	2420
4/13/93	2460
4/14/93	2180
4/15/93	2240
4/16/93	5060
4/17/93	5050
4/18/93	2360
4/19/93	2260
4/20/93	1810
4/21/93	1800
4/22/93	2010
4/23/93	2250
4/24/93	1820
4/25/93	1490
4/26/93	1660
4/27/93	2140
4/28/93	1820
4/29/93	1600
4/30/93	1410
5/1/93	1280
5/2/93	1270
5/3/93	1320
5/4/93	1230
5/5/93	0
5/6/93	4.3

Date	Flow (cfs)
5/7/93	1910
5/8/93	2090
5/9/93	2680
5/10/93	2560
5/11/93	1710
5/12/93	1610
5/13/93	1430
5/14/93	1670
5/15/93	1700
5/16/93	1800
5/17/93	1130
5/18/93	1150
5/19/93	1160
5/20/93	1340
5/21/93	1400
5/22/93	1480
5/23/93	1380
5/24/93	1300
5/25/93	1000
5/26/93	952
5/27/93	960
5/28/93	1010
5/29/93	952
5/30/93	1190
5/31/93	1480
6/1/93	792
6/2/93	643
6/3/93	441
6/4/93	514
6/5/93	1470
6/6/93	1740
6/7/93	1700
6/8/93	1530
6/9/93	1250
6/10/93	1480
6/11/93	1730
6/12/93	1200
6/13/93	717
6/14/93	469
6/15/93	446
6/16/93	457
6/17/93	492
6/18/93	483
6/19/93	460
6/20/93	494
6/21/93	677
6/22/93	910

Date	Flow (cfs)
6/23/93	921
6/24/93	840
6/25/93	656
6/26/93	588
6/27/93	537
6/28/93	533
6/29/93	428
6/30/93	434
7/1/93	533
7/2/93	2940
7/3/93	3820
7/4/93	1890
7/5/93	941
7/6/93	658
7/7/93	489
7/8/93	519
7/9/93	568
7/10/93	538
7/11/93	536
7/12/93	506
7/13/93	520
7/14/93	533
7/15/93	560
7/16/93	494
7/17/93	522
7/18/93	522
7/19/93	564
7/20/93	381
7/21/93	513
7/22/93	532
7/23/93	536
7/24/93	526
7/25/93	528
7/26/93	487
7/27/93	440
7/28/93	502
7/29/93	534
7/30/93	533
7/31/93	582
8/1/93	582
8/2/93	572
8/3/93	569
8/4/93	576
8/5/93	561
8/6/93	410
8/7/93	448
8/8/93	528

Date	Flow (cfs)
8/9/93	510
8/10/93	507
8/11/93	517
8/12/93	528
8/13/93	529
8/14/93	476
8/15/93	508
8/16/93	525
8/17/93	549
8/18/93	539
8/19/93	589
8/20/93	584
8/21/93	539
8/22/93	553
8/23/93	541
8/24/93	554
8/25/93	561
8/26/93	554
8/27/93	536
8/28/93	522
8/29/93	578
8/30/93	565
8/31/93	573
9/1/93	583
9/2/93	563
9/3/93	570
9/4/93	629
9/5/93	565
9/6/93	585
9/7/93	577
9/8/93	525
9/9/93	468
9/10/93	534
9/11/93	614
9/12/93	602
9/13/93	607
9/14/93	611
9/15/93	598
9/16/93	565
9/17/93	477
9/18/93	408
9/19/93	454
9/20/93	614
9/21/93	578
9/22/93	583
9/23/93	602
9/24/93	608

Date	Flow (cfs)
9/25/93	607
9/26/93	562
9/27/93	558
9/28/93	556
9/29/93	605
9/30/93	615
10/1/93	612
10/2/93	608
10/3/93	630
10/4/93	622
10/5/93	620
10/6/93	618
10/7/93	617
10/8/93	611
10/9/93	621
10/10/93	622
10/11/93	600
10/12/93	580
10/13/93	595
10/14/93	602
10/15/93	589
10/16/93	573
10/17/93	564
10/18/93	536
10/19/93	538
10/20/93	556
10/21/93	524
10/22/93	495
10/23/93	516
10/24/93	500
10/25/93	479
10/26/93	514
10/27/93	501
10/28/93	512
10/29/93	516
10/30/93	500
10/31/93	373
11/1/93	592
11/2/93	600
11/3/93	640
11/4/93	616
11/5/93	611
11/6/93	586
11/7/93	588
11/8/93	602
11/9/93	624
11/10/93	622

Date	Flow (cfs)
11/11/93	626
11/12/93	620
11/13/93	621
11/14/93	604
11/15/93	591
11/16/93	596
11/17/93	614
11/18/93	553
11/19/93	554
11/20/93	594
11/21/93	642
11/22/93	613
11/23/93	615
11/24/93	609
11/25/93	614
11/26/93	611
11/27/93	576
11/28/93	34.4
11/29/93	437
11/30/93	514
12/1/93	557
12/2/93	559
12/3/93	553
12/4/93	520
12/5/93	0
12/6/93	271
12/7/93	402
12/8/93	469
12/9/93	517
12/10/93	794
12/11/93	989
12/12/93	1150
12/13/93	701
12/14/93	678
12/15/93	815
12/16/93	1010
12/17/93	1460
12/18/93	1630
12/19/93	1340
12/20/93	877
12/21/93	612
12/22/93	759
12/23/93	774
12/24/93	723
12/25/93	714
12/26/93	711
12/27/93	583

Date	Flow (cfs)
12/28/93	568
12/29/93	554
12/30/93	597
12/31/93	657
1/1/94	619
1/2/94	615
1/3/94	607
1/4/94	1770
1/5/94	3880
1/6/94	1950
1/7/94	1180
1/8/94	1660
1/9/94	3150
1/10/94	1140
1/11/94	692
1/12/94	4040
1/13/94	7620
1/14/94	2550
1/15/94	1570
1/16/94	906
1/17/94	734
1/18/94	944
1/19/94	3250
1/20/94	5280
1/21/94	363
1/22/94	307
1/23/94	276
1/24/94	286
1/25/94	425
1/26/94	417
1/27/94	282
1/28/94	788
1/29/94	3410
1/30/94	2040
1/31/94	2040
2/1/94	2580
2/2/94	1880
2/3/94	1150
2/4/94	854
2/5/94	887
2/6/94	880
2/7/94	900
2/8/94	1130
2/9/94	2250
2/10/94	4070
2/11/94	5200
2/12/94	9140

Date	Flow (cfs)
2/13/94	4520
2/14/94	4100
2/15/94	3330
2/16/94	1750
2/17/94	2280
2/18/94	3140
2/19/94	3190
2/20/94	3210
2/21/94	3220
2/22/94	3230
2/23/94	5600
2/24/94	7920
2/25/94	5940
2/26/94	2400
2/27/94	1800
2/28/94	1550
3/1/94	4040
3/2/94	7000
3/3/94	8030
3/4/94	6000
3/5/94	3720
3/6/94	4210
3/7/94	4340
3/8/94	4360
3/9/94	4370
3/10/94	3630
3/11/94	2780
3/12/94	1680
3/13/94	1230
3/14/94	1640
3/15/94	1750
3/16/94	1780
3/17/94	1460
3/18/94	866
3/19/94	805
3/20/94	892
3/21/94	1060
3/22/94	1550
3/23/94	1450
3/24/94	1020
3/25/94	762
3/26/94	792
3/27/94	3410
3/28/94	6480
3/29/94	9770
3/30/94	11000
3/31/94	11200

Date	Flow (cfs)
4/1/94	7480
4/2/94	6450
4/3/94	2880
4/4/94	2190
4/5/94	1820
4/6/94	1820
4/7/94	1840
4/8/94	1560
4/9/94	1310
4/10/94	1290
4/11/94	1920
4/12/94	2670
4/13/94	302
4/14/94	309
4/15/94	797
4/16/94	959
4/17/94	783
4/18/94	798
4/19/94	795
4/20/94	985
4/21/94	1180
4/22/94	1200
4/23/94	1460
4/24/94	1010
4/25/94	827
4/26/94	804
4/27/94	750
4/28/94	663
4/29/94	747
4/30/94	2600
5/1/94	2890
5/2/94	1210
5/3/94	960
5/4/94	1300
5/5/94	2320
5/6/94	1940
5/7/94	1540
5/8/94	1260
5/9/94	1200
5/10/94	905
5/11/94	625
5/12/94	638
5/13/94	671
5/14/94	694
5/15/94	853
5/16/94	1100
5/17/94	1170

Date	Flow (cfs)
5/18/94	864
5/19/94	519
5/20/94	523
5/21/94	530
5/22/94	743
5/23/94	1210
5/24/94	818
5/25/94	693
5/26/94	644
5/27/94	557
5/28/94	603
5/29/94	830
5/30/94	1240
5/31/94	908
6/1/94	657
6/2/94	493
6/3/94	497
6/4/94	496
6/5/94	495
6/6/94	501
6/7/94	410
6/8/94	440
6/9/94	427
6/10/94	491
6/11/94	423
6/12/94	460
6/13/94	452
6/14/94	441
6/15/94	469
6/16/94	489
6/17/94	577
6/18/94	513
6/19/94	525
6/20/94	511
6/21/94	533
6/22/94	522
6/23/94	551
6/24/94	495
6/25/94	551
6/26/94	555
6/27/94	466
6/28/94	251
6/29/94	438
6/30/94	465
7/1/94	433
7/2/94	502
7/3/94	532

Date	Flow (cfs)
7/4/94	1610
7/5/94	1680
7/6/94	474
7/7/94	501
7/8/94	514
7/9/94	519
7/10/94	539
7/11/94	536
7/12/94	526
7/13/94	528
7/14/94	518
7/15/94	524
7/16/94	585
7/17/94	427
7/18/94	0
7/19/94	265
7/20/94	632
7/21/94	870
7/22/94	952
7/23/94	1200
7/24/94	853
7/25/94	446
7/26/94	621
7/27/94	2180
7/28/94	4140
7/29/94	6060
7/30/94	2130
7/31/94	778
8/1/94	384
8/2/94	147
8/3/94	1740
8/4/94	4200
8/5/94	1390
8/6/94	416
8/7/94	431
8/8/94	462
8/9/94	475
8/10/94	470
8/11/94	467
8/12/94	491
8/13/94	559
8/14/94	518
8/15/94	440
8/16/94	3320
8/17/94	7400
8/18/94	4860
8/19/94	302

Date	Flow (cfs)
8/20/94	329
8/21/94	1040
8/22/94	916
8/23/94	446
8/24/94	449
8/25/94	456
8/26/94	462
8/27/94	473
8/28/94	437
8/29/94	431
8/30/94	444
8/31/94	480
9/1/94	650
9/2/94	653
9/3/94	575
9/4/94	493
9/5/94	494
9/6/94	476
9/7/94	479
9/8/94	490
9/9/94	498
9/10/94	544
9/11/94	534
9/12/94	535
9/13/94	515
9/14/94	518
9/15/94	535
9/16/94	543
9/17/94	565
9/18/94	535
9/19/94	504
9/20/94	534
9/21/94	547
9/22/94	543
9/23/94	526
9/24/94	528
9/25/94	529
9/26/94	541
9/27/94	147
9/28/94	492
9/29/94	537
9/30/94	561
10/1/94	536
10/2/94	582
10/3/94	542
10/4/94	548
10/5/94	564

Date	Flow (cfs)
10/6/94	583
10/7/94	591
10/8/94	578
10/9/94	553
10/10/94	538
10/11/94	558
10/12/94	580
10/13/94	577
10/14/94	547
10/15/94	468
10/16/94	510
10/17/94	740
10/18/94	549
10/19/94	574
10/20/94	558
10/21/94	527
10/22/94	549
10/23/94	530
10/24/94	445
10/25/94	526
10/26/94	542
10/27/94	520
10/28/94	530
10/29/94	528
10/30/94	512
10/31/94	536
11/1/94	490
11/2/94	492
11/3/94	503
11/4/94	571
11/5/94	525
11/6/94	529
11/7/94	566
11/8/94	547
11/9/94	536
11/10/94	528
11/11/94	472
11/12/94	488
11/13/94	522
11/14/94	512
11/15/94	517
11/16/94	524
11/17/94	538
11/18/94	546
11/19/94	538
11/20/94	502
11/21/94	455

Date	Flow (cfs)
11/22/94	333
11/23/94	420
11/24/94	478
11/25/94	525
11/26/94	521
11/27/94	523
11/28/94	443
11/29/94	485
11/30/94	459
12/1/94	480
12/2/94	506
12/3/94	512
12/4/94	499
12/5/94	219
12/6/94	260
12/7/94	390
12/8/94	425
12/9/94	462
12/10/94	464
12/11/94	282
12/12/94	317
12/13/94	478
12/14/94	403
12/15/94	404
12/16/94	426
12/17/94	438
12/18/94	413
12/19/94	454
12/20/94	481
12/21/94	489
12/22/94	475
12/23/94	481
12/24/94	475
12/25/94	493
12/26/94	514
12/27/94	519
12/28/94	509
12/29/94	523
12/30/94	517
12/31/94	498
1/1/95	380
1/2/95	456
1/3/95	513
1/4/95	533
1/5/95	510
1/6/95	317
1/7/95	75

Date	Flow (cfs)
1/8/95	223
1/9/95	440
1/10/95	409
1/11/95	421
1/12/95	418
1/13/95	399
1/14/95	498
1/15/95	4590
1/16/95	7710
1/17/95	9850
1/18/95	6580
1/19/95	956
1/20/95	3310
1/21/95	2810
1/22/95	1410
1/23/95	294
1/24/95	408
1/25/95	1060
1/26/95	1130
1/27/95	1000
1/28/95	850
1/29/95	1210
1/30/95	984
1/31/95	895
2/1/95	769
2/2/95	650
2/3/95	916
2/4/95	1890
2/5/95	1470
2/6/95	493
2/7/95	902
2/8/95	1250
2/9/95	963
2/10/95	614
2/11/95	501
2/12/95	395
2/13/95	480
2/14/95	600
2/15/95	1380
2/16/95	3270
2/17/95	3880
2/18/95	4010
2/19/95	2340
2/20/95	1260
2/21/95	1110
2/22/95	1130
2/23/95	1180

Date	Flow (cfs)
2/24/95	929
2/25/95	848
2/26/95	811
2/27/95	635
2/28/95	1130
3/1/95	1680
3/2/95	1500
3/3/95	1340
3/4/95	1120
3/5/95	1020
3/6/95	754
3/7/95	667
3/8/95	3020
3/9/95	3130
3/10/95	1520
3/11/95	1450
3/12/95	1120
3/13/95	988
3/14/95	437
3/15/95	429
3/16/95	420
3/17/95	452
3/18/95	593
3/19/95	587
3/20/95	682
3/21/95	650
3/22/95	702
3/23/95	647
3/24/95	566
3/25/95	538
3/26/95	544
3/27/95	533
3/28/95	460
3/29/95	450
3/30/95	434
3/31/95	438
4/1/95	457
4/2/95	452
4/3/95	472
4/4/95	482
4/5/95	489
4/6/95	493
4/7/95	477
4/8/95	478
4/9/95	482
4/10/95	464
4/11/95	449

Date	Flow (cfs)
4/12/95	433
4/13/95	374
4/14/95	417
4/15/95	479
4/16/95	1210
4/17/95	1940
4/18/95	1500
4/19/95	1070
4/20/95	920
4/21/95	877
4/22/95	869
4/23/95	1130
4/24/95	1420
4/25/95	1030
4/26/95	860
4/27/95	874
4/28/95	895
4/29/95	908
4/30/95	1250
5/1/95	1480
5/2/95	861
5/3/95	703
5/4/95	782
5/5/95	778
5/6/95	832
5/7/95	850
5/8/95	873
5/9/95	893
5/10/95	605
5/11/95	562
5/12/95	718
5/13/95	816
5/14/95	856
5/15/95	857
5/16/95	851
5/17/95	869
5/18/95	890
5/19/95	826
5/20/95	797
5/21/95	865
5/22/95	896
5/23/95	917
5/24/95	513
5/25/95	506
5/26/95	487
5/27/95	433
5/28/95	316

Date	Flow (cfs)
5/29/95	352
5/30/95	440
5/31/95	506
6/1/95	527
6/2/95	488
6/3/95	359
6/4/95	286
6/5/95	405
6/6/95	489
6/7/95	411
6/8/95	428
6/9/95	424
6/10/95	516
6/11/95	0
6/12/95	224
6/13/95	824
6/14/95	972
6/15/95	528
6/16/95	421
6/17/95	334
6/18/95	421
6/19/95	466
6/20/95	531
6/21/95	507
6/22/95	855
6/23/95	21600
6/24/95	9330
6/25/95	8020
6/26/95	3640
6/27/95	5290
6/28/95	0
6/29/95	0
6/30/95	17700
7/1/95	15300
7/2/95	6110
7/3/95	1860
7/4/95	1520
7/5/95	1320
7/6/95	1000
7/7/95	1250
7/8/95	1650
7/9/95	1360
7/10/95	1030
7/11/95	604
7/12/95	476
7/13/95	481
7/14/95	497

Date	Flow (cfs)
7/15/95	634
7/16/95	490
7/17/95	473
7/18/95	353
7/19/95	527
7/20/95	614
7/21/95	461
7/22/95	379
7/23/95	497
7/24/95	409
7/25/95	313
7/26/95	1390
7/27/95	2050
7/28/95	2070
7/29/95	804
7/30/95	460
7/31/95	443
8/1/95	484
8/2/95	493
8/3/95	504
8/4/95	520
8/5/95	544
8/6/95	515
8/7/95	568
8/8/95	517
8/9/95	493
8/10/95	497
8/11/95	489
8/12/95	513
8/13/95	551
8/14/95	529
8/15/95	2200
8/16/95	4770
8/17/95	741
8/18/95	535
8/19/95	527
8/20/95	524
8/21/95	540
8/22/95	551
8/23/95	561
8/24/95	571
8/25/95	546
8/26/95	545
8/27/95	557
8/28/95	462
8/29/95	502
8/30/95	530

Date	Flow (cfs)
8/31/95	539
9/1/95	524
9/2/95	150
9/3/95	504
9/4/95	520
9/5/95	535
9/6/95	541
9/7/95	611
9/8/95	556
9/9/95	584
9/10/95	577
9/11/95	1120
9/12/95	1610
9/13/95	277
9/14/95	277
9/15/95	275
9/16/95	298
9/17/95	241
9/18/95	193
9/19/95	21.7
9/20/95	50
9/21/95	655
9/22/95	1710
9/23/95	553
9/24/95	549
9/25/95	530
9/26/95	488
9/27/95	469
9/28/95	541
9/29/95	526
9/30/95	552
10/1/95	523
10/2/95	584
10/3/95	536
10/4/95	529
10/5/95	0
10/6/95	108
10/7/95	469
10/8/95	459
10/9/95	497
10/10/95	536
10/11/95	535
10/12/95	545
10/13/95	994
10/14/95	373
10/15/95	161
10/16/95	440

Date	Flow (cfs)
10/17/95	516
10/18/95	528
10/19/95	535
10/20/95	281
10/21/95	327
10/22/95	470
10/23/95	494
10/24/95	514
10/25/95	520
10/26/95	518
10/27/95	524
10/28/95	485
10/29/95	498
10/30/95	517
10/31/95	537
11/1/95	528
11/2/95	518
11/3/95	539
11/4/95	560
11/5/95	513
11/6/95	553
11/7/95	496
11/8/95	342
11/9/95	458
11/10/95	489
11/11/95	0
11/12/95	0
11/13/95	286
11/14/95	455
11/15/95	417
11/16/95	468
11/17/95	501
11/18/95	528
11/19/95	524
11/20/95	517
11/21/95	536
11/22/95	507
11/23/95	512
11/24/95	517
11/25/95	490
11/26/95	544
11/27/95	571
11/28/95	536
11/29/95	182
11/30/95	427
12/1/95	490
12/2/95	494

Date	Flow (cfs)
12/3/95	519
12/4/95	489
12/5/95	504
12/6/95	519
12/7/95	483
12/8/95	508
12/9/95	436
12/10/95	505
12/11/95	514
12/12/95	358
12/13/95	208
12/14/95	354
12/15/95	853
12/16/95	845
12/17/95	744
12/18/95	549
12/19/95	373
12/20/95	315
12/21/95	540
12/22/95	898
12/23/95	770
12/24/95	786
12/25/95	709
12/26/95	527
12/27/95	392
12/28/95	420
12/29/95	429
12/30/95	418
12/31/95	446
1/1/96	507
1/2/96	496
1/3/96	468
1/4/96	503
1/5/96	501
1/6/96	504
1/7/96	790
1/8/96	1670
1/9/96	796
1/10/96	2930
1/11/96	2940
1/12/96	1260
1/13/96	1130
1/14/96	559
1/15/96	518
1/16/96	1160
1/17/96	2010
1/18/96	3190

Date	Flow (cfs)
1/19/96	2490
1/20/96	11500
1/21/96	13400
1/22/96	9100
1/23/96	4300
1/24/96	5140
1/25/96	544
1/26/96	4410
1/27/96	4420
1/28/96	6950
1/29/96	2060
1/30/96	2780
1/31/96	2520
2/1/96	2490
2/2/96	2270
2/3/96	2030
2/4/96	1750
2/5/96	1490
2/6/96	1460
2/7/96	1440
2/8/96	1280
2/9/96	5160
2/10/96	7750
2/11/96	3380
2/12/96	2830
2/13/96	2800
2/14/96	1890
2/15/96	1690
2/16/96	1730
2/17/96	1770
2/18/96	1530
2/19/96	786
2/20/96	618
2/21/96	1230
2/22/96	1820
2/23/96	1840
2/24/96	1870
2/25/96	1710
2/26/96	960
2/27/96	835
2/28/96	841
2/29/96	808
3/1/96	969
3/2/96	990
3/3/96	999
3/4/96	936
3/5/96	886

Date	Flow (cfs)
3/6/96	1340
3/7/96	1730
3/8/96	1100
3/9/96	1010
3/10/96	682
3/11/96	455
3/12/96	463
3/13/96	478
3/14/96	568
3/15/96	673
3/16/96	1700
3/17/96	2190
3/18/96	1800
3/19/96	2920
3/20/96	7210
3/21/96	3060
3/22/96	1110
3/23/96	1270
3/24/96	1540
3/25/96	1430
3/26/96	1250
3/27/96	1580
3/28/96	2330
3/29/96	3660
3/30/96	3270
3/31/96	2370
4/1/96	2240
4/2/96	3950
4/3/96	2520
4/4/96	1100
4/5/96	1180
4/6/96	1200
4/7/96	1200
4/8/96	1210
4/9/96	1220
4/10/96	1260
4/11/96	1250
4/12/96	1170
4/13/96	1010
4/14/96	933
4/15/96	862
4/16/96	982
4/17/96	1060
4/18/96	983
4/19/96	764
4/20/96	582
4/21/96	451

Date	Flow (cfs)
4/22/96	596
4/23/96	950
4/24/96	882
4/25/96	885
4/26/96	877
4/27/96	853
4/28/96	886
4/29/96	888
4/30/96	981
5/1/96	1410
5/2/96	1980
5/3/96	1250
5/4/96	958
5/5/96	895
5/6/96	3980
5/7/96	3490
5/8/96	2200
5/9/96	1530
5/10/96	1160
5/11/96	996
5/12/96	1360
5/13/96	1460
5/14/96	1070
5/15/96	947
5/16/96	1930
5/17/96	3690
5/18/96	1680
5/19/96	1510
5/20/96	1120
5/21/96	963
5/22/96	895
5/23/96	723
5/24/96	696
5/25/96	571
5/26/96	690
5/27/96	756
5/28/96	2250
5/29/96	1280
5/30/96	918
5/31/96	865
6/1/96	756
6/2/96	758
6/3/96	780
6/4/96	849
6/5/96	765
6/6/96	799
6/7/96	682

Date	Flow (cfs)
6/8/96	642
6/9/96	2690
6/10/96	8810
6/11/96	12400
6/12/96	6100
6/13/96	2460
6/14/96	1800
6/15/96	1470
6/16/96	1530
6/17/96	1010
6/18/96	660
6/19/96	463
6/20/96	1350
6/21/96	1400
6/22/96	1140
6/23/96	793
6/24/96	485
6/25/96	600
6/26/96	597
6/27/96	562
6/28/96	532
6/29/96	515
6/30/96	515
7/1/96	559
7/2/96	524
7/3/96	366
7/4/96	506
7/5/96	548
7/6/96	569
7/7/96	576
7/8/96	515
7/9/96	829
7/10/96	1300
7/11/96	1500
7/12/96	2270
7/13/96	561
7/14/96	593
7/15/96	278
7/16/96	452
7/17/96	601
7/18/96	511
7/19/96	552
7/20/96	578
7/21/96	562
7/22/96	559
7/23/96	569
7/24/96	573

Date	Flow (cfs)
7/25/96	570
7/26/96	449
7/27/96	502
7/28/96	588
7/29/96	562
7/30/96	458
7/31/96	538
8/1/96	707
8/2/96	589
8/3/96	524
8/4/96	398
8/5/96	502
8/6/96	656
8/7/96	593
8/8/96	501
8/9/96	476
8/10/96	461
8/11/96	515
8/12/96	3170
8/13/96	6170
8/14/96	7560
8/15/96	3140
8/16/96	1340
8/17/96	813
8/18/96	865
8/19/96	714
8/20/96	494
8/21/96	460
8/22/96	457
8/23/96	487
8/24/96	504
8/25/96	425
8/26/96	478
8/27/96	512
8/28/96	508
8/29/96	629
8/30/96	1070
8/31/96	1050
9/1/96	575
9/2/96	552
9/3/96	1360
9/4/96	7960
9/5/96	10300
9/6/96	0
9/7/96	9800
9/8/96	13400
9/9/96	11800

Date	Flow (cfs)
9/10/96	10200
9/11/96	4780
9/12/96	1910
9/13/96	1670
9/14/96	3290
9/15/96	1310
9/16/96	1270
9/17/96	1620
9/18/96	1540
9/19/96	1210
9/20/96	992
9/21/96	997
9/22/96	969
9/23/96	960
9/24/96	698
9/25/96	572
9/26/96	551
9/27/96	476
9/28/96	546
9/29/96	1430
9/30/96	1350
10/1/96	1470
10/2/96	1250
10/3/96	1040
10/4/96	682
10/5/96	519
10/6/96	435
10/7/96	570
10/8/96	2760
10/9/96	2340
10/10/96	828
10/11/96	998
10/12/96	773
10/13/96	873
10/14/96	793
10/15/96	614
10/16/96	662
10/17/96	801
10/18/96	926
10/19/96	915
10/20/96	895
10/21/96	884
10/22/96	838
10/23/96	767
10/24/96	555
10/25/96	488
10/26/96	494

Date	Flow (cfs)
10/27/96	481
10/28/96	501
10/29/96	507
10/30/96	505
10/31/96	570
11/1/96	567
11/2/96	589
11/3/96	543
11/4/96	479
11/5/96	444
11/6/96	469
11/7/96	448
11/8/96	1970
11/9/96	4610
11/10/96	3310
11/11/96	2150
11/12/96	1060
11/13/96	817
11/14/96	760
11/15/96	715
11/16/96	632
11/17/96	552
11/18/96	532
11/19/96	691
11/20/96	1100
11/21/96	1020
11/22/96	1130
11/23/96	1700
11/24/96	1660
11/25/96	648
11/26/96	550
11/27/96	1610
11/28/96	1250
11/29/96	1530
11/30/96	1530
12/1/96	4420
12/2/96	8900
12/3/96	9660
12/4/96	4660
12/5/96	3030
12/6/96	1300
12/7/96	1640
12/8/96	3630
12/9/96	3040
12/10/96	1810
12/11/96	1420
12/12/96	1370

Date	Flow (cfs)
12/13/96	2570
12/14/96	2790
12/15/96	1660
12/16/96	447
12/17/96	1380
12/18/96	1680
12/19/96	1610
12/20/96	1690
12/21/96	1240
12/22/96	1050
12/23/96	1020
12/24/96	999
12/25/96	947
12/26/96	1070
12/27/96	1200
12/28/96	1220
12/29/96	1210
12/30/96	1090
12/31/96	982
1/1/97	982
1/2/97	1040
1/3/97	1140
1/4/97	1120
1/5/97	1080
1/6/97	1260
1/7/97	1340
1/8/97	2190
1/9/97	1760
1/10/97	1060
1/11/97	874
1/12/97	723
1/13/97	552
1/14/97	561
1/15/97	545
1/16/97	629
1/17/97	1310
1/18/97	1390
1/19/97	1480
1/20/97	1490
1/21/97	1450
1/22/97	1390
1/23/97	1380
1/24/97	1570
1/25/97	2420
1/26/97	2640
1/27/97	1260
1/28/97	2470

Date	Flow (cfs)
1/29/97	3850
1/30/97	3340
1/31/97	1760
2/1/97	1190
2/2/97	1230
2/3/97	1360
2/4/97	1570
2/5/97	1530
2/6/97	1560
2/7/97	1420
2/8/97	1220
2/9/97	1090
2/10/97	1650
2/11/97	2450
2/12/97	1820
2/13/97	2590
2/14/97	2570
2/15/97	2460
2/16/97	3470
2/17/97	3930
2/18/97	2830
2/19/97	1530
2/20/97	1550
2/21/97	2160
2/22/97	3030
2/23/97	2270
2/24/97	1560
2/25/97	1730
2/26/97	1550
2/27/97	1300
2/28/97	1290
3/1/97	1740
3/2/97	3010
3/3/97	2260
3/4/97	2530
3/5/97	3800
3/6/97	3760
3/7/97	3970
3/8/97	4060
3/9/97	4130
3/10/97	4180
3/11/97	2600
3/12/97	1830
3/13/97	1460
3/14/97	1270
3/15/97	1460
3/16/97	1650

Date	Flow (cfs)
3/17/97	1380
3/18/97	944
3/19/97	1810
3/20/97	3390
3/21/97	2050
3/22/97	1290
3/23/97	1540
3/24/97	1370
3/25/97	682
3/26/97	706
3/27/97	890
3/28/97	944
3/29/97	964
3/30/97	972
3/31/97	912
4/1/97	1030
4/2/97	1170
4/3/97	1180
4/4/97	1110
4/5/97	978
4/6/97	959
4/7/97	922
4/8/97	975
4/9/97	909
4/10/97	543
4/11/97	480
4/12/97	547
4/13/97	1440
4/14/97	1250
4/15/97	953
4/16/97	952
4/17/97	964
4/18/97	940
4/19/97	969
4/20/97	999
4/21/97	1090
4/22/97	1530
4/23/97	2340
4/24/97	1190
4/25/97	1120
4/26/97	998
4/27/97	976
4/28/97	876
4/29/97	1150
4/30/97	3500
5/1/97	3890
5/2/97	2050

Date	Flow (cfs)
5/3/97	1480
5/4/97	1360
5/5/97	1070
5/6/97	1040
5/7/97	884
5/8/97	869
5/9/97	762
5/10/97	681
5/11/97	809
5/12/97	1070
5/13/97	892
5/14/97	676
5/15/97	663
5/16/97	679
5/17/97	688
5/18/97	891
5/19/97	1250
5/20/97	974
5/21/97	706
5/22/97	728
5/23/97	727
5/24/97	747
5/25/97	938
5/26/97	1230
5/27/97	1170
5/28/97	759
5/29/97	774
5/30/97	778
5/31/97	785
6/1/97	896
6/2/97	1640
6/3/97	5750
6/4/97	4660
6/5/97	1810
6/6/97	1380
6/7/97	1160
6/8/97	778
6/9/97	643
6/10/97	647
6/11/97	657
6/12/97	665
6/13/97	1010
6/14/97	1340
6/15/97	1310
6/16/97	763
6/17/97	607
6/18/97	505

Date	Flow (cfs)
6/19/97	532
6/20/97	714
6/21/97	746
6/22/97	997
6/23/97	682
6/24/97	567
6/25/97	615
6/26/97	849
6/27/97	1010
6/28/97	1170
6/29/97	1200
6/30/97	886
7/1/97	527
7/2/97	654
7/3/97	691
7/4/97	568
7/5/97	567
7/6/97	566
7/7/97	566
7/8/97	575
7/9/97	597
7/10/97	555
7/11/97	549
7/12/97	584
7/13/97	595
7/14/97	591
7/15/97	587
7/16/97	639
7/17/97	598
7/18/97	548
7/19/97	581
7/20/97	560
7/21/97	557
7/22/97	529
7/23/97	3520
7/24/97	867
7/25/97	573
7/26/97	564
7/27/97	570
7/28/97	526
7/29/97	571
7/30/97	532
7/31/97	481
8/1/97	552
8/2/97	577
8/3/97	604
8/4/97	610

Date	Flow (cfs)
8/5/97	527
8/6/97	577
8/7/97	628
8/8/97	627
8/9/97	612
8/10/97	582
8/11/97	604
8/12/97	621
8/13/97	619
8/14/97	651
8/15/97	629
8/16/97	629
8/17/97	600
8/18/97	606
8/19/97	648
8/20/97	516
8/21/97	423
8/22/97	589
8/23/97	643
8/24/97	620
8/25/97	635
8/26/97	655
8/27/97	627
8/28/97	633
8/29/97	630
8/30/97	649
8/31/97	659
9/1/97	692
9/2/97	632
9/3/97	655
9/4/97	657
9/5/97	655
9/6/97	631
9/7/97	666
9/8/97	655
9/9/97	687
9/10/97	594
9/11/97	69.6
9/12/97	507
9/13/97	519
9/14/97	550
9/15/97	536
9/16/97	559
9/17/97	555
9/18/97	529
9/19/97	526
9/20/97	550

Date	Flow (cfs)
9/21/97	556
9/22/97	544
9/23/97	558
9/24/97	542
9/25/97	495
9/26/97	515
9/27/97	539
9/28/97	503
9/29/97	445
9/30/97	506
10/1/97	540
10/2/97	547
10/3/97	556
10/4/97	553
10/5/97	543
10/6/97	543
10/7/97	544
10/8/97	562
10/9/97	586
10/10/97	564
10/11/97	562
10/12/97	558
10/13/97	560
10/14/97	568
10/15/97	562
10/16/97	553
10/17/97	558
10/18/97	544
10/19/97	501
10/20/97	485
10/21/97	538
10/22/97	535
10/23/97	561
10/24/97	538
10/25/97	515
10/26/97	535
10/27/97	421
10/28/97	547
10/29/97	517
10/30/97	522
10/31/97	523
11/1/97	394
11/2/97	483
11/3/97	419
11/4/97	466
11/5/97	531
11/6/97	534

Date	Flow (cfs)
11/7/97	545
11/8/97	519
11/9/97	542
11/10/97	531
11/11/97	554
11/12/97	552
11/13/97	538
11/14/97	467
11/15/97	459
11/16/97	477
11/17/97	492
11/18/97	538
11/19/97	525
11/20/97	541
11/21/97	537
11/22/97	490
11/23/97	533
11/24/97	512
11/25/97	544
11/26/97	548
11/27/97	543
11/28/97	546
11/29/97	533
11/30/97	547
12/1/97	525
12/2/97	518
12/3/97	522
12/4/97	513
12/5/97	505
12/6/97	511
12/7/97	528
12/8/97	520
12/9/97	536
12/10/97	527
12/11/97	501
12/12/97	520
12/13/97	536
12/14/97	521
12/15/97	505
12/16/97	531
12/17/97	509
12/18/97	526
12/19/97	538
12/20/97	550
12/21/97	559
12/22/97	519
12/23/97	435

Date	Flow (cfs)
12/24/97	465
12/25/97	378
12/26/97	386
12/27/97	426
12/28/97	348
12/29/97	412
12/30/97	417
12/31/97	450
1/1/98	493
1/2/98	478
1/3/98	473
1/4/98	466
1/5/98	448
1/6/98	473
1/7/98	467
1/8/98	0
1/9/98	0
1/10/98	234
1/11/98	385
1/12/98	955
1/13/98	1460
1/14/98	3050
1/15/98	1810
1/16/98	3720
1/17/98	3960
1/18/98	1470
1/19/98	865
1/20/98	1160
1/21/98	1140
1/22/98	3810
1/23/98	1430
1/24/98	2320
1/25/98	1730
1/26/98	1270
1/27/98	1410
1/28/98	0
1/29/98	11600
1/30/98	12300
1/31/98	9600
2/1/98	8220
2/2/98	4490
2/3/98	4090
2/4/98	901
2/5/98	7750
2/6/98	10500
2/7/98	9910
2/8/98	8750

Date	Flow (cfs)
2/9/98	8740
2/10/98	4860
2/11/98	1980
2/12/98	2800
2/13/98	2710
2/14/98	2190
2/15/98	1680
2/16/98	1240
2/17/98	3310
2/18/98	8190
2/19/98	10200
2/20/98	8550
2/21/98	4250
2/22/98	3060
2/23/98	5230
2/24/98	6340
2/25/98	2500
2/26/98	1660
2/27/98	1650
2/28/98	1660
3/1/98	1660
3/2/98	1510
3/3/98	1560
3/4/98	1580
3/5/98	1580
3/6/98	1240
3/7/98	944
3/8/98	656
3/9/98	809
3/10/98	3600
3/11/98	4120
3/12/98	4300
3/13/98	2720
3/14/98	952
3/15/98	923
3/16/98	1080
3/17/98	1340
3/18/98	1620
3/19/98	3160
3/20/98	4980
3/21/98	7340
3/22/98	11200
3/23/98	10300
3/24/98	4360
3/25/98	1830
3/26/98	1850
3/27/98	2050

Date	Flow (cfs)
3/28/98	2050
3/29/98	1480
3/30/98	1290
3/31/98	1310
4/1/98	1320
4/2/98	1500
4/3/98	1250
4/4/98	1850
4/5/98	2880
4/6/98	2240
4/7/98	1430
4/8/98	1090
4/9/98	1030
4/10/98	1410
4/11/98	1690
4/12/98	1460
4/13/98	1290
4/14/98	1240
4/15/98	1150
4/16/98	1120
4/17/98	3530
4/18/98	7960
4/19/98	1660
4/20/98	7110
4/21/98	9420
4/22/98	3190
4/23/98	2230
4/24/98	1990
4/25/98	1750
4/26/98	1570
4/27/98	1080
4/28/98	1080
4/29/98	982
4/30/98	1310
5/1/98	1870
5/2/98	2640
5/3/98	4140
5/4/98	2610
5/5/98	2280
5/6/98	2310
5/7/98	2230
5/8/98	2300
5/9/98	2220
5/10/98	1900
5/11/98	2010
5/12/98	3410
5/13/98	2320

Date	Flow (cfs)
5/14/98	1870
5/15/98	1670
5/16/98	1390
5/17/98	1340
5/18/98	1340
5/19/98	1270
5/20/98	1100
5/21/98	1050
5/22/98	984
5/23/98	907
5/24/98	1120
5/25/98	1240
5/26/98	1130
5/27/98	1310
5/28/98	2090
5/29/98	1550
5/30/98	1080
5/31/98	1140
6/1/98	1160
6/2/98	1070
6/3/98	927
6/4/98	906
6/5/98	906
6/6/98	919
6/7/98	921
6/8/98	827
6/9/98	637
6/10/98	566
6/11/98	509
6/12/98	1280
6/13/98	1360
6/14/98	975
6/15/98	743
6/16/98	644
6/17/98	481
6/18/98	756
6/19/98	693
6/20/98	605
6/21/98	623
6/22/98	629
6/23/98	495
6/24/98	411
6/25/98	450
6/26/98	445
6/27/98	462
6/28/98	883
6/29/98	597

Date	Flow (cfs)
6/30/98	608
7/1/98	552
7/2/98	460
7/3/98	430
7/4/98	431
7/5/98	390
7/6/98	418
7/7/98	436
7/8/98	403
7/9/98	399
7/10/98	318
7/11/98	391
7/12/98	408
7/13/98	432
7/14/98	430
7/15/98	420
7/16/98	430
7/17/98	208
7/18/98	366
7/19/98	446
7/20/98	427
7/21/98	453
7/22/98	462
7/23/98	405
7/24/98	423
7/25/98	464
7/26/98	457
7/27/98	483
7/28/98	472
7/29/98	460
7/30/98	453
7/31/98	482
8/1/98	465
8/2/98	479
8/3/98	489
8/4/98	492
8/5/98	503
8/6/98	505
8/7/98	512
8/8/98	571
8/9/98	107
8/10/98	356
8/11/98	396
8/12/98	451
8/13/98	470
8/14/98	473
8/15/98	483

Date	Flow (cfs)
8/16/98	1290
8/17/98	325
8/18/98	400
8/19/98	442
8/20/98	454
8/21/98	463
8/22/98	469
8/23/98	464
8/24/98	481
8/25/98	1670
8/26/98	1020
8/27/98	473
8/28/98	477
8/29/98	2020
8/30/98	554
8/31/98	502
9/1/98	508
9/2/98	514
9/3/98	541
9/4/98	519
9/5/98	517
9/6/98	505
9/7/98	521
9/8/98	532
9/9/98	525
9/10/98	539
9/11/98	577
9/12/98	548
9/13/98	555
9/14/98	551
9/15/98	552
9/16/98	560
9/17/98	561
9/18/98	525
9/19/98	551
9/20/98	593
9/21/98	549
9/22/98	518
9/23/98	503
9/24/98	523
9/25/98	537
9/26/98	553
9/27/98	535
9/28/98	555
9/29/98	626
9/30/98	543
10/1/98	539

Date	Flow (cfs)
10/2/98	549
10/3/98	590
10/4/98	575
10/5/98	568
10/6/98	557
10/7/98	543
10/8/98	526
10/9/98	416
10/10/98	517
10/11/98	561
10/12/98	549
10/13/98	556
10/14/98	565
10/15/98	568
10/16/98	572
10/17/98	575
10/18/98	580
10/19/98	573
10/20/98	576
10/21/98	580
10/22/98	600
10/23/98	590
10/24/98	585
10/25/98	589
10/26/98	566
10/27/98	572
10/28/98	569
10/29/98	580
10/30/98	566
10/31/98	589
11/1/98	599
11/2/98	553
11/3/98	564
11/4/98	540
11/5/98	542
11/6/98	568
11/7/98	584
11/8/98	564
11/9/98	566
11/10/98	582
11/11/98	515
11/12/98	503
11/13/98	510
11/14/98	541
11/15/98	573
11/16/98	601
11/17/98	520

Date	Flow (cfs)
11/18/98	568
11/19/98	547
11/20/98	544
11/21/98	547
11/22/98	557
11/23/98	551
11/24/98	543
11/25/98	564
11/26/98	542
11/27/98	543
11/28/98	554
11/29/98	561
11/30/98	561
12/1/98	578
12/2/98	586
12/3/98	555
12/4/98	524
12/5/98	581
12/6/98	575
12/7/98	560
12/8/98	555
12/9/98	447
12/10/98	453
12/11/98	506
12/12/98	549
12/13/98	296
12/14/98	137
12/15/98	450
12/16/98	469
12/17/98	465
12/18/98	369
12/19/98	382
12/20/98	386
12/21/98	377
12/22/98	386
12/23/98	383
12/24/98	327
12/25/98	164
12/26/98	213
12/27/98	234
12/28/98	234
12/29/98	244
12/30/98	255
12/31/98	272
1/1/99	279
1/2/99	273
1/3/99	1.3

Date	Flow (cfs)
1/4/99	0
1/5/99	92.4
1/6/99	153
1/7/99	148
1/8/99	222
1/9/99	202
1/10/99	78.7
1/11/99	133
1/12/99	194
1/13/99	208
1/14/99	186
1/15/99	93.4
1/16/99	61
1/17/99	146
1/18/99	27.1
1/19/99	0
1/20/99	80.1
1/21/99	144
1/22/99	177
1/23/99	195
1/24/99	0
1/25/99	0
1/26/99	28
1/27/99	109
1/28/99	149
1/29/99	182
1/30/99	208
1/31/99	211
2/1/99	215
2/2/99	0
2/3/99	0
2/4/99	38
2/5/99	113
2/6/99	162
2/7/99	183
2/8/99	177
2/9/99	207
2/10/99	223
2/11/99	226
2/12/99	228
2/13/99	213
2/14/99	231
2/15/99	268
2/16/99	246
2/17/99	247
2/18/99	195
2/19/99	4.1

Date	Flow (cfs)
2/20/99	104
2/21/99	158
2/22/99	188
2/23/99	231
2/24/99	239
2/25/99	244
2/26/99	244
2/27/99	257
2/28/99	244
3/1/99	286
3/2/99	477
3/3/99	464
3/4/99	437
3/5/99	470
3/6/99	509
3/7/99	513
3/8/99	500
3/9/99	460
3/10/99	454
3/11/99	462
3/12/99	476
3/13/99	487
3/14/99	485
3/15/99	1080
3/16/99	2440
3/17/99	2140
3/18/99	1410
3/19/99	1290
3/20/99	1150
3/21/99	1180
3/22/99	1710
3/23/99	1590
3/24/99	1240
3/25/99	836
3/26/99	664
3/27/99	537
3/28/99	522
3/29/99	471
3/30/99	496
3/31/99	497
4/1/99	475
4/2/99	735
4/3/99	990
4/4/99	1020
4/5/99	916
4/6/99	496
4/7/99	469

Date	Flow (cfs)
4/8/99	450
4/9/99	490
4/10/99	502
4/11/99	600
4/12/99	1830
4/13/99	2630
4/14/99	2260
4/15/99	1320
4/16/99	861
4/17/99	800
4/18/99	628
4/19/99	467
4/20/99	453
4/21/99	472
4/22/99	465
4/23/99	480
4/24/99	471
4/25/99	528
4/26/99	1260
4/27/99	1230
4/28/99	1070
4/29/99	981
4/30/99	897
5/1/99	907
5/2/99	981
5/3/99	1020
5/4/99	1150
5/5/99	1070
5/6/99	1010
5/7/99	1090
5/8/99	946
5/9/99	1020
5/10/99	1070
5/11/99	1090
5/12/99	1030
5/13/99	980
5/14/99	1120
5/15/99	802
5/16/99	831
5/17/99	986
5/18/99	984
5/19/99	945
5/20/99	944
5/21/99	990
5/22/99	1040
5/23/99	1040
5/24/99	1040

Date	Flow (cfs)
5/25/99	891
5/26/99	542
5/27/99	540
5/28/99	525
5/29/99	501
5/30/99	504
5/31/99	528
6/1/99	552
6/2/99	562
6/3/99	548
6/4/99	564
6/5/99	575
6/6/99	553
6/7/99	558
6/8/99	576
6/9/99	581
6/10/99	574
6/11/99	588
6/12/99	587
6/13/99	588
6/14/99	585
6/15/99	576
6/16/99	577
6/17/99	515
6/18/99	358
6/19/99	477
6/20/99	476
6/21/99	351
6/22/99	341
6/23/99	345
6/24/99	353
6/25/99	480
6/26/99	542
6/27/99	405
6/28/99	350
6/29/99	331
6/30/99	367
7/1/99	362
7/2/99	388
7/3/99	457
7/4/99	473
7/5/99	422
7/6/99	389
7/7/99	386
7/8/99	230
7/9/99	413
7/10/99	527

Date	Flow (cfs)
7/11/99	403
7/12/99	329
7/13/99	214
7/14/99	242
7/15/99	277
7/16/99	372
7/17/99	447
7/18/99	396
7/19/99	363
7/20/99	369
7/21/99	357
7/22/99	0
7/23/99	183
7/24/99	402
7/25/99	396
7/26/99	360
7/27/99	374
7/28/99	369
7/29/99	289
7/30/99	353
7/31/99	445
8/1/99	413
8/2/99	366
8/3/99	375
8/4/99	388
8/5/99	390
8/6/99	446
8/7/99	501
8/8/99	452
8/9/99	397
8/10/99	393
8/11/99	399
8/12/99	411
8/13/99	468
8/14/99	512
8/15/99	463
8/16/99	406
8/17/99	406
8/18/99	415
8/19/99	418
8/20/99	441
8/21/99	479
8/22/99	433
8/23/99	388
8/24/99	392
8/25/99	299
8/26/99	129

Date	Flow (cfs)
8/27/99	256
8/28/99	454
8/29/99	429
8/30/99	394
8/31/99	414
9/1/99	408
9/2/99	396
9/3/99	458
9/4/99	510
9/5/99	76.5
9/6/99	0
9/7/99	0
9/8/99	145
9/9/99	269
9/10/99	277
9/11/99	330
9/12/99	353
9/13/99	323
9/14/99	331
9/15/99	340
9/16/99	184
9/17/99	236
9/18/99	362
9/19/99	373
9/20/99	323
9/21/99	307
9/22/99	273
9/23/99	319
9/24/99	387
9/25/99	438
9/26/99	397
9/27/99	345
9/28/99	0
9/29/99	0
9/30/99	76.4
10/1/99	2310
10/2/99	357
10/3/99	421
10/4/99	467
10/5/99	468
10/6/99	500
10/7/99	522
10/8/99	540
10/9/99	540
10/10/99	512
10/11/99	484
10/12/99	519

Date	Flow (cfs)
10/13/99	546
10/14/99	555
10/15/99	561
10/16/99	563
10/17/99	561
10/18/99	561
10/19/99	569
10/20/99	550
10/21/99	468
10/22/99	510
10/23/99	539
10/24/99	555
10/25/99	561
10/26/99	760
10/27/99	562
10/28/99	529
10/29/99	534
10/30/99	535
10/31/99	538
11/1/99	505
11/2/99	473
11/3/99	320
11/4/99	364
11/5/99	441
11/6/99	436
11/7/99	437
11/8/99	442
11/9/99	443
11/10/99	446
11/11/99	450
11/12/99	458
11/13/99	454
11/14/99	455
11/15/99	459
11/16/99	469
11/17/99	486
11/18/99	481
11/19/99	469
11/20/99	462
11/21/99	463
11/22/99	420
11/23/99	369
11/24/99	427
11/25/99	449
11/26/99	437
11/27/99	362
11/28/99	380

Date	Flow (cfs)
11/29/99	412
11/30/99	443
12/1/99	455
12/2/99	447
12/3/99	459
12/4/99	455
12/5/99	451
12/6/99	436
12/7/99	425
12/8/99	444
12/9/99	449
12/10/99	434
12/11/99	388
12/12/99	424
12/13/99	429
12/14/99	0
12/15/99	0
12/16/99	170
12/17/99	322
12/18/99	463
12/19/99	500
12/20/99	587
12/21/99	726
12/22/99	709
12/23/99	626
12/24/99	569
12/25/99	577
12/26/99	556
12/27/99	544
12/28/99	545
12/29/99	537
12/30/99	548
12/31/99	497
1/1/00	434
1/2/00	436
1/3/00	428
1/4/00	428
1/5/00	372
1/6/00	418
1/7/00	420
1/8/00	426
1/9/00	416
1/10/00	0
1/11/00	587
1/12/00	2750
1/13/00	996
1/14/00	527

Date	Flow (cfs)
1/15/00	411
1/16/00	407
1/17/00	421
1/18/00	435
1/19/00	432
1/20/00	421
1/21/00	448
1/22/00	447
1/23/00	481
1/24/00	454
1/25/00	465
1/26/00	441
1/27/00	450
1/28/00	448
1/29/00	448
1/30/00	486
1/31/00	469
2/1/00	525
2/2/00	519
2/3/00	574
2/4/00	576
2/5/00	569
2/6/00	559
2/7/00	565
2/8/00	555
2/9/00	567
2/10/00	578
2/11/00	577
2/12/00	564
2/13/00	835
2/14/00	1060
2/15/00	1290
2/16/00	940
2/17/00	633
2/18/00	353
2/19/00	2670
2/20/00	3280
2/21/00	1350
2/22/00	1240
2/23/00	979
2/24/00	714
2/25/00	514
2/26/00	485
2/27/00	547
2/28/00	644
2/29/00	653
3/1/00	746

Date	Flow (cfs)
3/2/00	753
3/3/00	735
3/4/00	588
3/5/00	522
3/6/00	517
3/7/00	513
3/8/00	489
3/9/00	489
3/10/00	493
3/11/00	491
3/12/00	715
3/13/00	1130
3/14/00	651
3/15/00	469
3/16/00	469
3/17/00	468
3/18/00	627
3/19/00	673
3/20/00	824
3/21/00	5990
3/22/00	3360
3/23/00	2310
3/24/00	1430
3/25/00	1160
3/26/00	1230
3/27/00	1020
3/28/00	759
3/29/00	722
3/30/00	637
3/31/00	597
4/1/00	581
4/2/00	573
4/3/00	642
4/4/00	907
4/5/00	1270
4/6/00	1140
4/7/00	1200
4/8/00	575
4/9/00	675
4/10/00	790
4/11/00	558
4/12/00	570
4/13/00	579
4/14/00	570
4/15/00	569
4/16/00	869
4/17/00	722

Date	Flow (cfs)
4/18/00	5510
4/19/00	9620
4/20/00	5330
4/21/00	2520
4/22/00	1460
4/23/00	1150
4/24/00	1460
4/25/00	1340
4/26/00	2120
4/27/00	1890
4/28/00	1320
4/29/00	1130
4/30/00	1200
5/1/00	1330
5/2/00	1290
5/3/00	1190
5/4/00	1160
5/5/00	958
5/6/00	961
5/7/00	1070
5/8/00	1440
5/9/00	1400
5/10/00	1150
5/11/00	1080
5/12/00	1100
5/13/00	1120
5/14/00	1270
5/15/00	1530
5/16/00	1360
5/17/00	1090
5/18/00	1040
5/19/00	1060
5/20/00	1080
5/21/00	1270
5/22/00	958
5/23/00	1080
5/24/00	872
5/25/00	850
5/26/00	837
5/27/00	869
5/28/00	887
5/29/00	437
5/30/00	601
5/31/00	587
6/1/00	588
6/2/00	592
6/3/00	599

Date	Flow (cfs)
6/4/00	773
6/5/00	583
6/6/00	522
6/7/00	550
6/8/00	584
6/9/00	603
6/10/00	630
6/11/00	633
6/12/00	648
6/13/00	651
6/14/00	697
6/15/00	671
6/16/00	755
6/17/00	680
6/18/00	652
6/19/00	779
6/20/00	587
6/21/00	625
6/22/00	619
6/23/00	632
6/24/00	717
6/25/00	648
6/26/00	631
6/27/00	590
6/28/00	588
6/29/00	648
6/30/00	620
7/1/00	630
7/2/00	637
7/3/00	634
7/4/00	648
7/5/00	634
7/6/00	588
7/7/00	635
7/8/00	646
7/9/00	637
7/10/00	730
7/11/00	674
7/12/00	645
7/13/00	672
7/14/00	605
7/15/00	622
7/16/00	662
7/17/00	632
7/18/00	656
7/19/00	655
7/20/00	579

Date	Flow (cfs)
7/21/00	713
7/22/00	681
7/23/00	651
7/24/00	375
7/25/00	468
7/26/00	667
7/27/00	646
7/28/00	611
7/29/00	689
7/30/00	472
7/31/00	716
8/1/00	698
8/2/00	1660
8/3/00	2330
8/4/00	1120
8/5/00	647
8/6/00	666
8/7/00	666
8/8/00	675
8/9/00	666
8/10/00	652
8/11/00	677
8/12/00	724
8/13/00	680
8/14/00	676
8/15/00	677
8/16/00	678
8/17/00	680
8/18/00	698
8/19/00	691
8/20/00	687
8/21/00	680
8/22/00	684
8/23/00	709
8/24/00	689
8/25/00	700
8/26/00	690
8/27/00	677
8/28/00	360
8/29/00	558
8/30/00	634
8/31/00	649
9/1/00	954
9/2/00	560
9/3/00	0
9/4/00	1310
9/5/00	246

Date	Flow (cfs)
9/6/00	902
9/7/00	760
9/8/00	603
9/9/00	615
9/10/00	629
9/11/00	655
9/12/00	640
9/13/00	649
9/14/00	664
9/15/00	674
9/16/00	669
9/17/00	694
9/18/00	697
9/19/00	208
9/20/00	4120
9/21/00	1690
9/22/00	936
9/23/00	760
9/24/00	503
9/25/00	478
9/26/00	902
9/27/00	1220
9/28/00	1180
9/29/00	857
9/30/00	528
10/1/00	515
10/2/00	522
10/3/00	540
10/4/00	541
10/5/00	544
10/6/00	547
10/7/00	561
10/8/00	560
10/9/00	648
10/10/00	559
10/11/00	563
10/12/00	562
10/13/00	564
10/14/00	564
10/15/00	559
10/16/00	561
10/17/00	558
10/18/00	561
10/19/00	572
10/20/00	563
10/21/00	567
10/22/00	562

Date	Flow (cfs)
10/23/00	596
10/24/00	567
10/25/00	553
10/26/00	548
10/27/00	538
10/28/00	557
10/29/00	558
10/30/00	562
10/31/00	569
11/1/00	562
11/2/00	547
11/3/00	536
11/4/00	541
11/5/00	545
11/6/00	543
11/7/00	548
11/8/00	545
11/9/00	537
11/10/00	471
11/11/00	485
11/12/00	522
11/13/00	545
11/14/00	540
11/15/00	535
11/16/00	547
11/17/00	556
11/18/00	543
11/19/00	551
11/20/00	546
11/21/00	550
11/22/00	571
11/23/00	549
11/24/00	560
11/25/00	540
11/26/00	450
11/27/00	433
11/28/00	503
11/29/00	507
11/30/00	517
12/1/00	460
12/2/00	425
12/3/00	342
12/4/00	304
12/5/00	312
12/6/00	311
12/7/00	314
12/8/00	311

Date	Flow (cfs)
12/9/00	321
12/10/00	316
12/11/00	304
12/12/00	313
12/13/00	322
12/14/00	314
12/15/00	302
12/16/00	295
12/17/00	40.7
12/18/00	119
12/19/00	218
12/20/00	270
12/21/00	288
12/22/00	321
12/23/00	291
12/24/00	291
12/25/00	312
12/26/00	300
12/27/00	325
12/28/00	328
12/29/00	325
12/30/00	346
12/31/00	318
1/1/01	338
1/2/01	349
1/3/01	352
1/4/01	345
1/5/01	344
1/6/01	336
1/7/01	323
1/8/01	332
1/9/01	346
1/10/01	338
1/11/01	333
1/12/01	331
1/13/01	419
1/14/01	453
1/15/01	553
1/16/01	618
1/17/01	566
1/18/01	577
1/19/01	474
1/20/01	83
1/21/01	182
1/22/01	277
1/23/01	316
1/24/01	241

Date	Flow (cfs)
1/25/01	232
1/26/01	248
1/27/01	262
1/28/01	272
1/29/01	261
1/30/01	262
1/31/01	240
2/1/01	257
2/2/01	269
2/3/01	284
2/4/01	282
2/5/01	285
2/6/01	305
2/7/01	295
2/8/01	293
2/9/01	295
2/10/01	298
2/11/01	300
2/12/01	299
2/13/01	301
2/14/01	294
2/15/01	290
2/16/01	286
2/17/01	174
2/18/01	159
2/19/01	218
2/20/01	245
2/21/01	262
2/22/01	265
2/23/01	263
2/24/01	256
2/25/01	242
2/26/01	206
2/27/01	230
2/28/01	250
3/1/01	255
3/2/01	259
3/3/01	266
3/4/01	250
3/5/01	220
3/6/01	241
3/7/01	388
3/8/01	399
3/9/01	412
3/10/01	414
3/11/01	416
3/12/01	410

Date	Flow (cfs)
3/13/01	383
3/14/01	374
3/15/01	403
3/16/01	650
3/17/01	847
3/18/01	871
3/19/01	556
3/20/01	280
3/21/01	2380
3/22/01	5390
3/23/01	3230
3/24/01	2490
3/25/01	924
3/26/01	566
3/27/01	591
3/28/01	582
3/29/01	1050
3/30/01	6060
3/31/01	6840
4/1/01	2040
4/2/01	2700
4/3/01	3750
4/4/01	2380
4/5/01	743
4/6/01	570
4/7/01	571
4/8/01	551
4/9/01	732
4/10/01	884
4/11/01	802
4/12/01	980
4/13/01	1170
4/14/01	994
4/15/01	657
4/16/01	500
4/17/01	514
4/18/01	508
4/19/01	518
4/20/01	533
4/21/01	534
4/22/01	618
4/23/01	828
4/24/01	915
4/25/01	954
4/26/01	967
4/27/01	997
4/28/01	992

Date	Flow (cfs)
4/29/01	1080
4/30/01	1310
5/1/01	1190
5/2/01	1000
5/3/01	1010
5/4/01	1050
5/5/01	1050
5/6/01	1320
5/7/01	1830
5/8/01	1790
5/9/01	1650
5/10/01	1050
5/11/01	1040
5/12/01	1090
5/13/01	1140
5/14/01	1180
5/15/01	1210
5/16/01	922
5/17/01	670
5/18/01	779
5/19/01	849
5/20/01	634
5/21/01	893
5/22/01	0
5/23/01	4310
5/24/01	1950
5/25/01	1110
5/26/01	1360
5/27/01	2120
5/28/01	1720
5/29/01	1330
5/30/01	1160
5/31/01	1030
6/1/01	998
6/2/01	859
6/3/01	991
6/4/01	990
6/5/01	805
6/6/01	466
6/7/01	562
6/8/01	537
6/9/01	577
6/10/01	604
6/11/01	618
6/12/01	605
6/13/01	613
6/14/01	615

Date	Flow (cfs)
6/15/01	623
6/16/01	633
6/17/01	641
6/18/01	637
6/19/01	649
6/20/01	645
6/21/01	653
6/22/01	619
6/23/01	671
6/24/01	546
6/25/01	587
6/26/01	616
6/27/01	622
6/28/01	594
6/29/01	602
6/30/01	648
7/1/01	661
7/2/01	634
7/3/01	669
7/4/01	673
7/5/01	568
7/6/01	607
7/7/01	621
7/8/01	628
7/9/01	554
7/10/01	671
7/11/01	645
7/12/01	633
7/13/01	636
7/14/01	648
7/15/01	643
7/16/01	648
7/17/01	666
7/18/01	662
7/19/01	634
7/20/01	648
7/21/01	688
7/22/01	683
7/23/01	672
7/24/01	648
7/25/01	641
7/26/01	630
7/27/01	644
7/28/01	678
7/29/01	912
7/30/01	533
7/31/01	588

Date	Flow (cfs)
8/1/01	591
8/2/01	605
8/3/01	612
8/4/01	623
8/5/01	642
8/6/01	631
8/7/01	642
8/8/01	611
8/9/01	610
8/10/01	640
8/11/01	653
8/12/01	705
8/13/01	661
8/14/01	611
8/15/01	637
8/16/01	630
8/17/01	649
8/18/01	661
8/19/01	652
8/20/01	615
8/21/01	648
8/22/01	647
8/23/01	660
8/24/01	629
8/25/01	574
8/26/01	627
8/27/01	651
8/28/01	597
8/29/01	616
8/30/01	652
8/31/01	656
9/1/01	672
9/2/01	656
9/3/01	645
9/4/01	557
9/5/01	582
9/6/01	575
9/7/01	567
9/8/01	611
9/9/01	512
9/10/01	511
9/11/01	605
9/12/01	525
9/13/01	525
9/14/01	559
9/15/01	626
9/16/01	566

Date	Flow (cfs)
9/17/01	566
9/18/01	561
9/19/01	577
9/20/01	564
9/21/01	561
9/22/01	623
9/23/01	566
9/24/01	554
9/25/01	428
9/26/01	503
9/27/01	556
9/28/01	618
9/29/01	623
9/30/01	594
10/1/01	592
10/2/01	603
10/3/01	606
10/4/01	605
10/5/01	641
10/6/01	641
10/7/01	610
10/8/01	608
10/9/01	605
10/10/01	604
10/11/01	596
10/12/01	633
10/13/01	547
10/14/01	476
10/15/01	458
10/16/01	416
10/17/01	465
10/18/01	484
10/19/01	711
10/20/01	497
10/21/01	414
10/22/01	413
10/23/01	407
10/24/01	412
10/25/01	413
10/26/01	410
10/27/01	413
10/28/01	411
10/29/01	406
10/30/01	413
10/31/01	382
11/1/01	384
11/2/01	382

Date	Flow (cfs)
11/3/01	382
11/4/01	380
11/5/01	366
11/6/01	378
11/7/01	375
11/8/01	378
11/9/01	373
11/10/01	377
11/11/01	373
11/12/01	371
11/13/01	381
11/14/01	373
11/15/01	375
11/16/01	370
11/17/01	377
11/18/01	371
11/19/01	366
11/20/01	363
11/21/01	371
11/22/01	374
11/23/01	370
11/24/01	366
11/25/01	348
11/26/01	342
11/27/01	343
11/28/01	352
11/29/01	364
11/30/01	366
12/1/01	359
12/2/01	360
12/3/01	370
12/4/01	614
12/5/01	410
12/6/01	350
12/7/01	349
12/8/01	349
12/9/01	340
12/10/01	342
12/11/01	30.8
12/12/01	140
12/13/01	267
12/14/01	300
12/15/01	315
12/16/01	320
12/17/01	312
12/18/01	294
12/19/01	282

Date	Flow (cfs)
12/20/01	312
12/21/01	314
12/22/01	318
12/23/01	324
12/24/01	307
12/25/01	294
12/26/01	306
12/27/01	304
12/28/01	309
12/29/01	309
12/30/01	320
12/31/01	308
1/1/02	334
1/2/02	340
1/3/02	354
1/4/02	339
1/5/02	324
1/6/02	351
1/7/02	345
1/8/02	225
1/9/02	233
1/10/02	238
1/11/02	261
1/12/02	264
1/13/02	248
1/14/02	256
1/15/02	251
1/16/02	265
1/17/02	262
1/18/02	257
1/19/02	254
1/20/02	211
1/21/02	191
1/22/02	173
1/23/02	91.3
1/24/02	0
1/25/02	35.5
1/26/02	79.4
1/27/02	127
1/28/02	169
1/29/02	177
1/30/02	186
1/31/02	187
2/1/02	189
2/2/02	213
2/3/02	222
2/4/02	220

Date	Flow (cfs)
2/5/02	222
2/6/02	235
2/7/02	169
2/8/02	121
2/9/02	131
2/10/02	163
2/11/02	170
2/12/02	180
2/13/02	187
2/14/02	197
2/15/02	206
2/16/02	211
2/17/02	213
2/18/02	227
2/19/02	228
2/20/02	228
2/21/02	227
2/22/02	222
2/23/02	230
2/24/02	228
2/25/02	234
2/26/02	243
2/27/02	242
2/28/02	245
3/1/02	252
3/2/02	249
3/3/02	20.8
3/4/02	50.1
3/5/02	228
3/6/02	242
3/7/02	181
3/8/02	216
3/9/02	225
3/10/02	216
3/11/02	230
3/12/02	231
3/13/02	202
3/14/02	159
3/15/02	179
3/16/02	195
3/17/02	93.3
3/18/02	0
3/19/02	0
3/20/02	0
3/21/02	80.8
3/22/02	145
3/23/02	179

Date	Flow (cfs)
3/24/02	159
3/25/02	153
3/26/02	170
3/27/02	121
3/28/02	146
3/29/02	168
3/30/02	164
3/31/02	89.4
4/1/02	45.1
4/2/02	112
4/3/02	132
4/4/02	157
4/5/02	161
4/6/02	168
4/7/02	174
4/8/02	179
4/9/02	206
4/10/02	199
4/11/02	199
4/12/02	215
4/13/02	216
4/14/02	204
4/15/02	192
4/16/02	205
4/17/02	217
4/18/02	225
4/19/02	657
4/20/02	754
4/21/02	780
4/22/02	760
4/23/02	832
4/24/02	851
4/25/02	847
4/26/02	812
4/27/02	828
4/28/02	873
4/29/02	830
4/30/02	860
5/1/02	836
5/2/02	568
5/3/02	321
5/4/02	757
5/5/02	987
5/6/02	847
5/7/02	799
5/8/02	1040
5/9/02	1170

Date	Flow (cfs)
5/10/02	1130
5/11/02	1270
5/12/02	1350
5/13/02	1360
5/14/02	1210
5/15/02	1120
5/16/02	875
5/17/02	897
5/18/02	862
5/19/02	773
5/20/02	808
5/21/02	800
5/22/02	752
5/23/02	614
5/24/02	576
5/25/02	574
5/26/02	574
5/27/02	571
5/28/02	401
5/29/02	506
5/30/02	520
5/31/02	593
6/1/02	620
6/2/02	771
6/3/02	881
6/4/02	816
6/5/02	640
6/6/02	652
6/7/02	633
6/8/02	628
6/9/02	636
6/10/02	645
6/11/02	654
6/12/02	667
6/13/02	666
6/14/02	668
6/15/02	481
6/16/02	357
6/17/02	363
6/18/02	361
6/19/02	361
6/20/02	357
6/21/02	470
6/22/02	555
6/23/02	370
6/24/02	370
6/25/02	369

Date	Flow (cfs)
6/26/02	372
6/27/02	375
6/28/02	364
6/29/02	438
6/30/02	350
7/1/02	381
7/2/02	417
7/3/02	426
7/4/02	428
7/5/02	491
7/6/02	489
7/7/02	433
7/8/02	422
7/9/02	449
7/10/02	450
7/11/02	425
7/12/02	472
7/13/02	448
7/14/02	408
7/15/02	391
7/16/02	380
7/17/02	400
7/18/02	416
7/19/02	490
7/20/02	494
7/21/02	425
7/22/02	422
7/23/02	427
7/24/02	431
7/25/02	308
7/26/02	174
7/27/02	388
7/28/02	327
7/29/02	394
7/30/02	416
7/31/02	421
8/1/02	423
8/2/02	517
8/3/02	474
8/4/02	439
8/5/02	443
8/6/02	433
8/7/02	449
8/8/02	459
8/9/02	543
8/10/02	491
8/11/02	451

Date	Flow (cfs)
8/12/02	447
8/13/02	453
8/14/02	451
8/15/02	447
8/16/02	546
8/17/02	511
8/18/02	429
8/19/02	430
8/20/02	430
8/21/02	445
8/22/02	445
8/23/02	541
8/24/02	494
8/25/02	439
8/26/02	433
8/27/02	428
8/28/02	430
8/29/02	354
8/30/02	446
8/31/02	455
9/1/02	348
9/2/02	304
9/3/02	343
9/4/02	362
9/5/02	365
9/6/02	463
9/7/02	425
9/8/02	374
9/9/02	371
9/10/02	378
9/11/02	380
9/12/02	376
9/13/02	377
9/14/02	385
9/15/02	378
9/16/02	323
9/17/02	284
9/18/02	340
9/19/02	359
9/20/02	360
9/21/02	362
9/22/02	363
9/23/02	352
9/24/02	364
9/25/02	363
9/26/02	345
9/27/02	199

Date	Flow (cfs)
9/28/02	175
9/29/02	222
9/30/02	271
10/1/02	305
10/2/02	313
10/3/02	320
10/4/02	318
10/5/02	373
10/6/02	377
10/7/02	404
10/8/02	376
10/9/02	370
10/10/02	372
10/11/02	348
10/12/02	217
10/13/02	260
10/14/02	295
10/15/02	312
10/16/02	250
10/17/02	6
10/18/02	190
10/19/02	248
10/20/02	274
10/21/02	283
10/22/02	277
10/23/02	278
10/24/02	287
10/25/02	294
10/26/02	290
10/27/02	306
10/28/02	293
10/29/02	121
10/30/02	0
10/31/02	3.5
11/1/02	155
11/2/02	207
11/3/02	230
11/4/02	244
11/5/02	240
11/6/02	49.1
11/7/02	122
11/8/02	186
11/9/02	217
11/10/02	226
11/11/02	0
11/12/02	0
11/13/02	0

Date	Flow (cfs)
11/14/02	22.8
11/15/02	143
11/16/02	49.7
11/17/02	0
11/18/02	312
11/19/02	427
11/20/02	517
11/21/02	931
11/22/02	1230
11/23/02	1110
11/24/02	702
11/25/02	594
11/26/02	601
11/27/02	613
11/28/02	616
11/29/02	620
11/30/02	624
12/1/02	631
12/2/02	594
12/3/02	480
12/4/02	492
12/5/02	442
12/6/02	404
12/7/02	457
12/8/02	428
12/9/02	448
12/10/02	457
12/11/02	297
12/12/02	428
12/13/02	1200
12/14/02	4160
12/15/02	3920
12/16/02	1490
12/17/02	1250
12/18/02	1080
12/19/02	957
12/20/02	884
12/21/02	2120
12/22/02	1530
12/23/02	1030
12/24/02	977
12/25/02	4970
12/26/02	4080
12/27/02	1220
12/28/02	1080
12/29/02	1040
12/30/02	1040

Date	Flow (cfs)
12/31/02	1090
1/1/03	1350
1/2/03	2080
1/3/03	1930
1/4/03	3670
1/5/03	1230
1/6/03	853
1/7/03	990
1/8/03	882
1/9/03	757
1/10/03	765
1/11/03	916
1/12/03	1330
1/13/03	1030
1/14/03	682
1/15/03	660
1/16/03	599
1/17/03	599
1/18/03	597
1/19/03	601
1/20/03	590
1/21/03	611
1/22/03	610
1/23/03	636
1/24/03	596
1/25/03	597
1/26/03	616
1/27/03	626
1/28/03	624
1/29/03	586
1/30/03	583
1/31/03	571
2/1/03	574
2/2/03	570
2/3/03	587
2/4/03	557
2/5/03	505
2/6/03	583
2/7/03	634
2/8/03	712
2/9/03	729
2/10/03	767
2/11/03	841
2/12/03	1040
2/13/03	1120
2/14/03	1080
2/15/03	916

Date	Flow (cfs)
2/16/03	4410
2/17/03	4630
2/18/03	2410
2/19/03	1720
2/20/03	2940
2/21/03	5200
2/22/03	777
2/23/03	9640
2/24/03	14600
2/25/03	13300
2/26/03	5110
2/27/03	3120
2/28/03	2500
3/1/03	2230
3/2/03	2120
3/3/03	2100
3/4/03	2160
3/5/03	2140
3/6/03	1950
3/7/03	1720
3/8/03	1470
3/9/03	1430
3/10/03	1280
3/11/03	1280
3/12/03	1040
3/13/03	944
3/14/03	753
3/15/03	686
3/16/03	651
3/17/03	616
3/18/03	784
3/19/03	925
3/20/03	0
3/21/03	8120
3/22/03	12000
3/23/03	3500
3/24/03	1870
3/25/03	1960
3/26/03	1930
3/27/03	1720
3/28/03	1420
3/29/03	1250
3/30/03	948
3/31/03	1100
4/1/03	1990
4/2/03	2560
4/3/03	3010

Date	Flow (cfs)
4/4/03	2820
4/5/03	1970
4/6/03	1970
4/7/03	1800
4/8/03	5350
4/9/03	7440
4/10/03	8390
4/11/03	8780
4/12/03	10900
4/13/03	4490
4/14/03	2240
4/15/03	2330
4/16/03	2290
4/17/03	2120
4/18/03	1890
4/19/03	1960
4/20/03	2080
4/21/03	2130
4/22/03	2180
4/23/03	1910
4/24/03	1570
4/25/03	1590
4/26/03	1370
4/27/03	1380
4/28/03	1190
4/29/03	1320
4/30/03	1090
5/1/03	912
5/2/03	1060
5/3/03	1200
5/4/03	1710
5/5/03	3890
5/6/03	3410
5/7/03	2350
5/8/03	1890
5/9/03	1520
5/10/03	1320
5/11/03	1570
5/12/03	1560
5/13/03	1580
5/14/03	1390
5/15/03	1150
5/16/03	1140
5/17/03	1320
5/18/03	2760
5/19/03	8760
5/20/03	8310

Date	Flow (cfs)
5/21/03	5150
5/22/03	4010
5/23/03	3400
5/24/03	2770
5/25/03	1830
5/26/03	2570
5/27/03	3260
5/28/03	3480
5/29/03	3850
5/30/03	3840
5/31/03	3770
6/1/03	3160
6/2/03	2960
6/3/03	2170
6/4/03	1950
6/5/03	1780
6/6/03	2300
6/7/03	3170
6/8/03	6490
6/9/03	7210
6/10/03	4250
6/11/03	2290
6/12/03	1950
6/13/03	1950
6/14/03	0
6/15/03	7420
6/16/03	6120
6/17/03	7320
6/18/03	7470
6/19/03	7060
6/20/03	7540
6/21/03	4840
6/22/03	3140
6/23/03	2200
6/24/03	1600
6/25/03	1360
6/26/03	1340
6/27/03	889
6/28/03	890
6/29/03	1340
6/30/03	1310
7/1/03	1980
7/2/03	4040
7/3/03	6140
7/4/03	6020
7/5/03	3220
7/6/03	2150

Date	Flow (cfs)
7/7/03	2840
7/8/03	3090
7/9/03	2500
7/10/03	2180
7/11/03	1850
7/12/03	1970
7/13/03	1830
7/14/03	2040
7/15/03	2210
7/16/03	1590
7/17/03	1360
7/18/03	1260
7/19/03	1210
7/20/03	1020
7/21/03	784
7/22/03	831
7/23/03	1280
7/24/03	1550
7/25/03	1660
7/26/03	1230
7/27/03	1090
7/28/03	879
7/29/03	840
7/30/03	1090
7/31/03	1320
8/1/03	1350
8/2/03	1420
8/3/03	1840
8/4/03	3780
8/5/03	3160
8/6/03	1960
8/7/03	2390
8/8/03	2800
8/9/03	2560
8/10/03	6560
8/11/03	8550
8/12/03	6480
8/13/03	1760
8/14/03	1570
8/15/03	1350
8/16/03	605
8/17/03	852
8/18/03	1900
8/19/03	2360
8/20/03	2290
8/21/03	1980
8/22/03	1590

Date	Flow (cfs)
8/23/03	1430
8/24/03	1030
8/25/03	1070
8/26/03	899
8/27/03	758
8/28/03	693
8/29/03	649
8/30/03	724
8/31/03	979
9/1/03	1160
9/2/03	1090
9/3/03	1030
9/4/03	968
9/5/03	1020
9/6/03	1380
9/7/03	1400
9/8/03	1130
9/9/03	978
9/10/03	725
9/11/03	662
9/12/03	668
9/13/03	660
9/14/03	606
9/15/03	659
9/16/03	878
9/17/03	1380
9/18/03	3050
9/19/03	2920
9/20/03	3490
9/21/03	1560
9/22/03	834
9/23/03	0
9/24/03	3410
9/25/03	3730
9/26/03	3830
9/27/03	2370
9/28/03	794
9/29/03	898
9/30/03	523
10/1/03	560
10/2/03	575
10/3/03	581
10/4/03	575
10/5/03	569
10/6/03	587
10/7/03	603
10/8/03	607

Date	Flow (cfs)
10/9/03	629
10/10/03	661
10/11/03	668
10/12/03	789
10/13/03	807
10/14/03	823
10/15/03	812
10/16/03	1080
10/17/03	991
10/18/03	827
10/19/03	824
10/20/03	660
10/21/03	766
10/22/03	820
10/23/03	824
10/24/03	833
10/25/03	715
10/26/03	608
10/27/03	574
10/28/03	956
10/29/03	1010
10/30/03	1050
10/31/03	1060
11/1/03	1070
11/2/03	973
11/3/03	652
11/4/03	569
11/5/03	579
11/6/03	630
11/7/03	2490
11/8/03	3550
11/9/03	1950
11/10/03	1080
11/11/03	874
11/12/03	731
11/13/03	642
11/14/03	707
11/15/03	676
11/16/03	625
11/17/03	605
11/18/03	834
11/19/03	3060
11/20/03	3180
11/21/03	3720
11/22/03	3840
11/23/03	2580
11/24/03	912

Date	Flow (cfs)
11/25/03	1030
11/26/03	1070
11/27/03	1100
11/28/03	1040
11/29/03	1020
11/30/03	1140
12/1/03	1090
12/2/03	1140
12/3/03	1160
12/4/03	1160
12/5/03	1180
12/6/03	1460
12/7/03	1590
12/8/03	1710
12/9/03	1670
12/10/03	1170
12/11/03	3560
12/12/03	7020
12/13/03	4650
12/14/03	2200
12/15/03	2080
12/16/03	1900
12/17/03	1720
12/18/03	2880
12/19/03	2540
12/20/03	1970
12/21/03	1590
12/22/03	1320
12/23/03	1320
12/24/03	1270
12/25/03	1180
12/26/03	1070
12/27/03	895
12/28/03	729
12/29/03	605
12/30/03	737
12/31/03	941
1/1/04	930
1/2/04	921
1/3/04	944
1/4/04	933
1/5/04	1050
1/6/04	1450
1/7/04	1570
1/8/04	1430
1/9/04	1310
1/10/04	1340

Date	Flow (cfs)
1/11/04	1210
1/12/04	1010
1/13/04	1030
1/14/04	1040
1/15/04	1030
1/16/04	1060
1/17/04	972
1/18/04	839
1/19/04	946
1/20/04	1050
1/21/04	979
1/22/04	902
1/23/04	937
1/24/04	908
1/25/04	949
1/26/04	1230
1/27/04	1670
1/28/04	1650
1/29/04	1440
1/30/04	1040
1/31/04	1010
2/1/04	828
2/2/04	831
2/3/04	692
2/4/04	2690
2/5/04	3850
2/6/04	2410
2/7/04	2980
2/8/04	3590
2/9/04	3820
2/10/04	3360
2/11/04	2780
2/12/04	2600
2/13/04	2080
2/14/04	1980
2/15/04	1790
2/16/04	1730
2/17/04	1840
2/18/04	1880
2/19/04	1710
2/20/04	1390
2/21/04	1120
2/22/04	1110
2/23/04	1100
2/24/04	1120
2/25/04	1140
2/26/04	1130

Date	Flow (cfs)
2/27/04	1120
2/28/04	1010
2/29/04	973
3/1/04	900
3/2/04	805
3/3/04	818
3/4/04	917
3/5/04	1060
3/6/04	1140
3/7/04	1380
3/8/04	1370
3/9/04	1230
3/10/04	1110
3/11/04	899
3/12/04	753
3/13/04	672
3/14/04	568
3/15/04	526
3/16/04	764
3/17/04	1170
3/18/04	1550
3/19/04	1600
3/20/04	1600
3/21/04	1360
3/22/04	1130
3/23/04	850
3/24/04	795
3/25/04	792
3/26/04	795
3/27/04	794
3/28/04	780
3/29/04	851
3/30/04	983
3/31/04	1200
4/1/04	1320
4/2/04	1250
4/3/04	1160
4/4/04	1070
4/5/04	831
4/6/04	683
4/7/04	642
4/8/04	536
4/9/04	508
4/10/04	776
4/11/04	861
4/12/04	862
4/13/04	4210

Date	Flow (cfs)
4/14/04	6060
4/15/04	7110
4/16/04	7580
4/17/04	4090
4/18/04	1710
4/19/04	1190
4/20/04	1240
4/21/04	1420
4/22/04	1390
4/23/04	1170
4/24/04	962
4/25/04	968
4/26/04	1040
4/27/04	1490
4/28/04	1410
4/29/04	1140
4/30/04	1060
5/1/04	1040
5/2/04	1150
5/3/04	1360
5/4/04	1160
5/5/04	981
5/6/04	886
5/7/04	839
5/8/04	859
5/9/04	954
5/10/04	1670
5/11/04	1240
5/12/04	965
5/13/04	956
5/14/04	965
5/15/04	965
5/16/04	1120
5/17/04	1230
5/18/04	868
5/19/04	673
5/20/04	524
5/21/04	613
5/22/04	541
5/23/04	746
5/24/04	699
5/25/04	655
5/26/04	619
5/27/04	898
5/28/04	1260
5/29/04	1030
5/30/04	844

Date	Flow (cfs)
5/31/04	520
6/1/04	630
6/2/04	676
6/3/04	632
6/4/04	728
6/5/04	2720
6/6/04	2840
6/7/04	1130
6/8/04	795
6/9/04	661
6/10/04	589
6/11/04	720
6/12/04	824
6/13/04	830
6/14/04	721
6/15/04	530
6/16/04	831
6/17/04	1590
6/18/04	1260
6/19/04	880
6/20/04	867
6/21/04	651
6/22/04	496
6/23/04	457
6/24/04	405
6/25/04	548
6/26/04	1470
6/27/04	2050
6/28/04	1240
6/29/04	944
6/30/04	672
7/1/04	586
7/2/04	566
7/3/04	526
7/4/04	530
7/5/04	520
7/6/04	541
7/7/04	535
7/8/04	464
7/9/04	449
7/10/04	469
7/11/04	180
7/12/04	295
7/13/04	250
7/14/04	396
7/15/04	420
7/16/04	408

Date	Flow (cfs)
7/17/04	497
7/18/04	447
7/19/04	443
7/20/04	439
7/21/04	453
7/22/04	463
7/23/04	466
7/24/04	566
7/25/04	683
7/26/04	570
7/27/04	464
7/28/04	598
7/29/04	633
7/30/04	654
7/31/04	843
8/1/04	868
8/2/04	0
8/3/04	1150
8/4/04	1550
8/5/04	1640
8/6/04	1490
8/7/04	1280
8/8/04	1100
8/9/04	510
8/10/04	526
8/11/04	527
8/12/04	484
8/13/04	2110
8/14/04	1680
8/15/04	511
8/16/04	506
8/17/04	548
8/18/04	423
8/19/04	473
8/20/04	497
8/21/04	518
8/22/04	462
8/23/04	505
8/24/04	548
8/25/04	535
8/26/04	539
8/27/04	546
8/28/04	557
8/29/04	522
8/30/04	528
8/31/04	541
9/1/04	560

Date	Flow (cfs)
9/2/04	566
9/3/04	568
9/4/04	575
9/5/04	570
9/6/04	562
9/7/04	2330
9/8/04	4770
9/9/04	3180
9/10/04	7570
9/11/04	6090
9/12/04	1880
9/13/04	980
9/14/04	1120
9/15/04	3580
9/16/04	6330
9/17/04	3630
9/18/04	0
9/19/04	314
9/20/04	478
9/21/04	523
9/22/04	532
9/23/04	509
9/24/04	519
9/25/04	530
9/26/04	515
9/27/04	523
9/28/04	0
9/29/04	7840
9/30/04	12700
10/1/04	13300
10/2/04	8770
10/3/04	2980
10/4/04	1740
10/5/04	1620
10/6/04	1290
10/7/04	914
10/8/04	844
10/9/04	713
10/10/04	689
10/11/04	687
10/12/04	714
10/13/04	802
10/14/04	2090
10/15/04	2070
10/16/04	1320
10/17/04	882
10/18/04	526

Date	Flow (cfs)
10/19/04	504
10/20/04	483
10/21/04	601
10/22/04	771
10/23/04	797
10/24/04	763
10/25/04	759
10/26/04	891
10/27/04	909
10/28/04	904
10/29/04	914
10/30/04	911
10/31/04	886
11/1/04	921
11/2/04	923
11/3/04	913
11/4/04	914
11/5/04	954
11/6/04	1040
11/7/04	1040
11/8/04	953
11/9/04	791
11/10/04	787
11/11/04	789
11/12/04	767
11/13/04	2010
11/14/04	2800
11/15/04	2060
11/16/04	1560
11/17/04	1300
11/18/04	996
11/19/04	790
11/20/04	727
11/21/04	739
11/22/04	763
11/23/04	1030
11/24/04	3090
11/25/04	6910
11/26/04	7250
11/27/04	1920
11/28/04	955
11/29/04	1580
11/30/04	1690
12/1/04	1590
12/2/04	1660
12/3/04	1740
12/4/04	1770

Date	Flow (cfs)
12/5/04	1740
12/6/04	1850
12/7/04	1820
12/8/04	1830
12/9/04	1590
12/10/04	1780
12/11/04	2340
12/12/04	2660
12/13/04	2750
12/14/04	2800
12/15/04	2120
12/16/04	1280
12/17/04	1020
12/18/04	941
12/19/04	776
12/20/04	808
12/21/04	646
12/22/04	676
12/23/04	333
12/24/04	1940
12/25/04	2350
12/26/04	2390
12/27/04	1610
12/28/04	1140
12/29/04	1010
12/30/04	994
12/31/04	950
1/1/05	918
1/2/05	794
1/3/05	800
1/4/05	869
1/5/05	860
1/6/05	862
1/7/05	867
1/8/05	853
1/9/05	858
1/10/05	853
1/11/05	869
1/12/05	869
1/13/05	845
1/14/05	1750
1/15/05	7600
1/16/05	7770
1/17/05	3410
1/18/05	2610
1/19/05	1480
1/20/05	1400

Date	Flow (cfs)
1/21/05	1360
1/22/05	1400
1/23/05	1430
1/24/05	1180
1/25/05	953
1/26/05	901
1/27/05	898
1/28/05	912
1/29/05	853
1/30/05	781
1/31/05	852
2/1/05	1090
2/2/05	1120
2/3/05	1110
2/4/05	1080
2/5/05	1080
2/6/05	1060
2/7/05	1080
2/8/05	1110
2/9/05	1120
2/10/05	1120
2/11/05	1150
2/12/05	1140
2/13/05	1140
2/14/05	1110
2/15/05	1110
2/16/05	1150
2/17/05	1180
2/18/05	1120
2/19/05	1040
2/20/05	1220
2/21/05	1020
2/22/05	1030
2/23/05	1250
2/24/05	1060
2/25/05	1060
2/26/05	1070
2/27/05	1050
2/28/05	1110
3/1/05	1310
3/2/05	1610
3/3/05	1630
3/4/05	1590
3/5/05	1170
3/6/05	1110
3/7/05	1250
3/8/05	1570

Date	Flow (cfs)
3/9/05	2030
3/10/05	2220
3/11/05	1810
3/12/05	1640
3/13/05	1410
3/14/05	1330
3/15/05	1200
3/16/05	1200
3/17/05	1270
3/18/05	1840
3/19/05	1760
3/20/05	1750
3/21/05	1790
3/22/05	1570
3/23/05	1460
3/24/05	1860
3/25/05	2460
3/26/05	2460
3/27/05	2210
3/28/05	2780
3/29/05	7120
3/30/05	7880
3/31/05	7990
4/1/05	7730
4/2/05	4910
4/3/05	2800
4/4/05	1990
4/5/05	1500
4/6/05	1540
4/7/05	1270
4/8/05	1220
4/9/05	1060
4/10/05	996
4/11/05	970
4/12/05	847
4/13/05	1010
4/14/05	1400
4/15/05	1290
4/16/05	1230
4/17/05	945
4/18/05	804
4/19/05	779
4/20/05	672
4/21/05	679
4/22/05	776
4/23/05	1100
4/24/05	1500

Date	Flow (cfs)
4/25/05	1430
4/26/05	1330
4/27/05	1050
4/28/05	1010
4/29/05	1040
4/30/05	1300.77375
5/1/05	1597.103333
5/2/05	1854.819167
5/3/05	1385.877917
5/4/05	1327.253333
5/5/05	1323.80875
5/6/05	1326.300833
5/7/05	1327.145833
5/8/05	1575.189583
5/9/05	1831.683333
5/10/05	1574.207917
5/11/05	1381.790417
5/12/05	1388.108333
5/13/05	1381.47
5/14/05	1372.16125
5/15/05	1635.91125
5/16/05	1868.330833
5/17/05	1458.33125
5/18/05	1386.17375
5/19/05	1360.85875
5/20/05	1210.9575
5/21/05	1106.574583
5/22/05	1228.659583
5/23/05	1307.67625
5/24/05	1308.082083
5/25/05	1318.594167
5/26/05	1277.1125
5/27/05	1037.732917
5/28/05	945.4929167
5/29/05	936.6554167
5/30/05	948.1108333
5/31/05	670.34125
6/1/05	671.4358333
6/2/05	668.05125
6/3/05	667.7554167
6/4/05	671.3133333
6/5/05	677.3670833
6/6/05	671.0504167
6/7/05	656.6258333
6/8/05	674.335
6/9/05	672.9333333
6/10/05	924.9175

Date	Flow (cfs)
6/11/05	1133.304583
6/12/05	970.2491667
6/13/05	893.1345833
6/14/05	850.7275
6/15/05	722.0566667
6/16/05	673.1754167
6/17/05	669.8204167
6/18/05	658.2316667
6/19/05	649.6125
6/20/05	658.7716667
6/21/05	653.4841667
6/22/05	655.3704167
6/23/05	655.1175
6/24/05	991.67125
6/25/05	745.3929167
6/26/05	656.4066667
6/27/05	678.1020833
6/28/05	663.2533333
6/29/05	669.23375
6/30/05	656.05625
7/1/05	653.6066667
7/2/05	655.7616667
7/3/05	649.8941667
7/4/05	661.5783333
7/5/05	665.6725
7/6/05	1334.127917
7/7/05	3641.80625
7/8/05	3168.88375
7/9/05	898.6954167
7/10/05	883.9904167
7/11/05	659.9570833
7/12/05	663.5670833
7/13/05	662.9620833
7/14/05	659.2745833
7/15/05	887.4183333
7/16/05	904.5304167
7/17/05	652.5441667
7/18/05	399.8429167
7/19/05	397.0483333
7/20/05	400.2429167
7/21/05	1424.687917
7/22/05	2497.489583
7/23/05	2883.215
7/24/05	1104.236667
7/25/05	303.095
7/26/05	320.6725
7/27/05	338.9229167

Date	Flow (cfs)
7/28/05	308.1054167
7/29/05	306.7175
7/30/05	1452.03625
7/31/05	1541.762917
8/1/05	844.5029167
8/2/05	820.2633333
8/3/05	823.7379167
8/4/05	823.7325
8/5/05	821.7058333
8/6/05	810.9954167
8/7/05	804.4391667
8/8/05	963.7070833
8/9/05	1045.2575
8/10/05	1207.147083
8/11/05	1277.247917
8/12/05	829.2558333
8/13/05	663.0833333
8/14/05	659.595
8/15/05	661.0729167
8/16/05	659.0225
8/17/05	668.0970833
8/18/05	660.1575
8/19/05	660.3583333
8/20/05	657.7720833
8/21/05	662.545
8/22/05	661.1233333
8/23/05	660.3454167
8/24/05	660.08
8/25/05	658.2241667
8/26/05	806.855
8/27/05	873.2858333
8/28/05	1026.102083
8/29/05	1802.437083
8/30/05	1262.242083
8/31/05	659.7754167
9/1/05	654.5883333
9/2/05	656.1020833
9/3/05	657.5779167
9/4/05	653.7083333
9/5/05	648.5254167
9/6/05	656.3320833
9/7/05	658.5166667
9/8/05	663.1891667
9/9/05	662.9825
9/10/05	658.23375
9/11/05	650.7958333
9/12/05	652.24875

Date	Flow (cfs)
9/13/05	656.66
9/14/05	661.58
9/15/05	651.5408333
9/16/05	652.8670833
9/17/05	651.5358333
9/18/05	638.9916667
9/19/05	656.1204167
9/20/05	647.4845833
9/21/05	653.0104167
9/22/05	655.5758333
9/23/05	656.5575
9/24/05	656.27125
9/25/05	659.5354167
9/26/05	658.98875
9/27/05	661.5470833
9/28/05	663.7979167
9/29/05	668.3083333
9/30/05	664.9283333
10/1/05	657.2175
10/2/05	655.6275
10/3/05	661.6991667
10/4/05	661.9891667
10/5/05	671.7770833
10/6/05	651.4958333
10/7/05	651.54125
10/8/05	4656.087083
10/9/05	5031.565833
10/10/05	800.5816667
10/11/05	989.77625
10/12/05	1082.014167
10/13/05	1041.74625
10/14/05	891.8454167
10/15/05	889.1983333
10/16/05	706.6654167
10/17/05	677.5445833
10/18/05	658.1416667
10/19/05	666.3125
10/20/05	654.33375
10/21/05	654.27625
10/22/05	659.9920833
10/23/05	659.1441667
10/24/05	664.3645833
10/25/05	676.98625
10/26/05	671.2991667
10/27/05	1810.335417
10/28/05	2003.629167
10/29/05	744.7216667

Date	Flow (cfs)
10/30/05	697.7141667
10/31/05	669.14
11/1/05	658.77
11/2/05	666.99625
11/3/05	665.2529167
11/4/05	663.50625
11/5/05	652.3166667
11/6/05	636.8470833
11/7/05	663.5245833
11/8/05	686.4258333
11/9/05	659.82
11/10/05	662.6975
11/11/05	660.99875
11/12/05	658.1483333
11/13/05	641.6408333
11/14/05	661.1891667
11/15/05	734.3491667
11/16/05	679.7545833
11/17/05	694.5829167
11/18/05	692.7425
11/19/05	663.72625
11/20/05	649.6483333
11/21/05	654.70625
11/22/05	668.0433333
11/23/05	666.38375
11/24/05	662.5108333
11/25/05	659.8245833
11/26/05	664.9320833
11/27/05	656.6941667
11/28/05	649.98125
11/29/05	1449.252917
11/30/05	4210.505
12/1/05	4284.600833
12/2/05	4340.3425
12/3/05	2427.522083
12/4/05	1161.259167
12/5/05	1387.915
12/6/05	1636.909583
12/7/05	1672.374167
12/8/05	1246.925
12/9/05	773.0775
12/10/05	777.5995833
12/11/05	758.9175
12/12/05	1024.7525
12/13/05	1262.114167
12/14/05	1266.077917
12/15/05	1497.355417

Date	Flow (cfs)
12/16/05	2191.76375
12/17/05	2293.515
12/18/05	1663.779583
12/19/05	1614.5225
12/20/05	1230.882917
12/21/05	1223.518333
12/22/05	1228.795417
12/23/05	870.5495833
12/24/05	864.36
12/25/05	888.2729167
12/26/05	1049.727917
12/27/05	1346.708333
12/28/05	1442.466667
12/29/05	1458.785
12/30/05	1436.122083
12/31/05	1437.00875
1/1/06	1429.654583
1/2/06	1426.415417
1/3/06	1436.125833
1/4/06	1447.877083
1/5/06	1376.585417
1/6/06	1069.779167
1/7/06	865.54
1/8/06	841.1925
1/9/06	845.7020833
1/10/06	883.84875
1/11/06	997.3591667
1/12/06	1079.43375
1/13/06	1071.247917
1/14/06	3008.708333
1/15/06	4481.328333
1/16/06	3874.341667
1/17/06	4520.070833
1/18/06	3300.78875
1/19/06	2388.790833
1/20/06	1877.17375
1/21/06	1883.75375
1/22/06	1872.57625
1/23/06	1877.770417
1/24/06	1787.88875
1/25/06	1409.46
1/26/06	1279.240833
1/27/06	1213.016667
1/28/06	1033.327083
1/29/06	1033.051667
1/30/06	1054.797917
1/31/06	1068.025

Date	Flow (cfs)
2/1/06	1088.852083
2/2/06	885.6283333
2/3/06	993.0883333
2/4/06	1203.939167
2/5/06	1730.22
2/6/06	1736.350417
2/7/06	1738.525
2/8/06	1735.58625
2/9/06	1625.61375
2/10/06	1258.227083
2/11/06	1259.441667
2/12/06	1236.3625
2/13/06	1233.825417
2/14/06	1258.388333
2/15/06	1246.5725
2/16/06	1151.820833
2/17/06	1004.527917
2/18/06	1043.424167
2/19/06	1031.607083
2/20/06	1030.298333
2/21/06	1033.370833
2/22/06	1045.468333
2/23/06	1095.622917
2/24/06	1022.85625
2/25/06	173.5245833
2/26/06	0
2/27/06	0
2/28/06	854.1008333
3/1/06	897.6654167
3/2/06	659.3479167
3/3/06	663.77
3/4/06	667.385
3/5/06	656.95125
3/6/06	669.8370833
3/7/06	673.3566667
3/8/06	658.69125
3/9/06	662.2129167
3/10/06	660.0308333
3/11/06	648.9279167
3/12/06	674.57625
3/13/06	667.8654167
3/14/06	718.74625
3/15/06	663.6266667
3/16/06	659.5975
3/17/06	663.4933333
3/18/06	666.6379167
3/19/06	676.6983333

Date	Flow (cfs)
3/20/06	691.46125
3/21/06	716.67875
3/22/06	641.775
3/23/06	668.0045833
3/24/06	690.3854167
3/25/06	669.0679167
3/26/06	667.99125
3/27/06	665.6920833
3/28/06	663.6966667
3/29/06	728.4008333
3/30/06	694.2920833
3/31/06	664.26125
4/1/06	678.5883333
4/2/06	653.13
4/3/06	661.7883333
4/4/06	681.82
4/5/06	659.0604167
4/6/06	675.6845833
4/7/06	672.91375
4/8/06	661.9254167
4/9/06	656.2166667
4/10/06	656.1379167
4/11/06	655.3408333
4/12/06	656.0583333
4/13/06	661.9020833
4/14/06	656.64375
4/15/06	670.0029167
4/16/06	1463.185833
4/17/06	1881.735
4/18/06	1415.867083
4/19/06	1270.630833
4/20/06	1154.959583
4/21/06	1157.766667
4/22/06	1225.592917
4/23/06	1331.438333
4/24/06	1404.84625
4/25/06	1120.744167
4/26/06	744.93
4/27/06	677.6545833
4/28/06	676.76125
4/29/06	712.4516667
4/30/06	1009.55125
5/1/06	1675.473333
5/2/06	755.6295833
5/3/06	663.31
5/4/06	654.1020833
5/5/06	653.0279167

Date	Flow (cfs)
5/6/06	706.9741667
5/7/06	1097.700833
5/8/06	1195.07875
5/9/06	845.7104167
5/10/06	683.37
5/11/06	678.7475
5/12/06	677.9483333
5/13/06	652.0625
5/14/06	968.68
5/15/06	1210.739583
5/16/06	1390.205
5/17/06	1629.130417
5/18/06	1552.335417
5/19/06	1472.654583
5/20/06	1518.977917
5/21/06	1570.305417
5/22/06	1566.590833
5/23/06	1052.517917
5/24/06	616.1033333
5/25/06	510.0804167
5/26/06	375
5/27/06	375
5/28/06	611.99625
5/29/06	651.37375
5/30/06	660.2395833
5/31/06	661.44625
6/1/06	631.9220833
6/2/06	653.4120833
6/3/06	647.3558333
6/4/06	648.6704167
6/5/06	682.77375
6/6/06	678.41125
6/7/06	657.5433333
6/8/06	656.0095833
6/9/06	661.3125
6/10/06	681.8279167
6/11/06	658.2595833
6/12/06	664.705
6/13/06	665.7920833
6/14/06	695.87625
6/15/06	687.2966667
6/16/06	671.5741667
6/17/06	656.66625
6/18/06	675.95125
6/19/06	650.0545833
6/20/06	598.6854167
6/21/06	609.6920833

Date	Flow (cfs)
6/22/06	621.3283333
6/23/06	817.07625
6/24/06	645.75625
6/25/06	615.6408333
6/26/06	923.14
6/27/06	10202.73708
6/28/06	10856.20667
6/29/06	8391.823333
6/30/06	3722.47375
7/1/06	1970.200833
7/2/06	724.5466667
7/3/06	719.28875
7/4/06	716.2904167
7/5/06	664.1145833
7/6/06	1043.454167
7/7/06	1584.2075
7/8/06	1592.604167
7/9/06	1099.834167
7/10/06	737.5608333
7/11/06	655.5033333
7/12/06	638.4945833
7/13/06	661.1066667
7/14/06	687.3075
7/15/06	660.2295833
7/16/06	655.0825
7/17/06	1324.402917
7/18/06	1781.445417
7/19/06	1711.545
7/20/06	821.5366667
7/21/06	708.6570833
7/22/06	672.7995833
7/23/06	670.7441667
7/24/06	664.51125
7/25/06	680.8241667
7/26/06	675.9645833
7/27/06	657.30125
7/28/06	666.8691667
7/29/06	658.4291667
7/30/06	2436.840417
7/31/06	674.9879167
8/1/06	686.2520833
8/2/06	669.5666667
8/3/06	695.8766667
8/4/06	678.24375
8/5/06	675.86125
8/6/06	658.4183333
8/7/06	647.8404167

Date	Flow (cfs)
8/8/06	655.4845833
8/9/06	657.3129167
8/10/06	747.3729167
8/11/06	632.6820833
8/12/06	620.55375
8/13/06	640.5833333
8/14/06	666.8695833
8/15/06	656.7441667
8/16/06	657.2216667
8/17/06	660.9116667
8/18/06	649.65875
8/19/06	663.38125
8/20/06	724.58375
8/21/06	651.79125
8/22/06	682.945
8/23/06	672.6508333
8/24/06	652.1320833
8/25/06	678.6775
8/26/06	681.84125
8/27/06	655.7908333
8/28/06	666.8316667
8/29/06	665.1658333
8/30/06	723.6483333
8/31/06	662.7291667
9/1/06	664.6629167
9/2/06	659.6720833
9/3/06	664.2795833
9/4/06	663.9433333
9/5/06	1440.145833
9/6/06	2301.673333
9/7/06	1474.228333
9/8/06	892.32375
9/9/06	793.6129167
9/10/06	787.25
9/11/06	710.2579167
9/12/06	668.68
9/13/06	904.9379167
9/14/06	1258.458333
9/15/06	1916.25375
9/16/06	1909.76
9/17/06	1800.56375
9/18/06	980.6120833
9/19/06	658.08625
9/20/06	645.9204167
9/21/06	651.1716667
9/22/06	658.78
9/23/06	667.3658333

Date	Flow (cfs)
9/24/06	665.76
9/25/06	660.7545833
9/26/06	657.25625
9/27/06	656.5820833
9/28/06	664.1395833
9/29/06	664.6654167
9/30/06	664.7895833
10/1/06	664.675
10/2/06	665.8045833
10/3/06	667.8858333
10/4/06	673
10/5/06	660.5133333
10/6/06	656.7854167
10/7/06	1485.738333
10/8/06	1829.443333
10/9/06	1826.84
10/10/06	1616.44375
10/11/06	790.8345833
10/12/06	676.97375
10/13/06	676.6691667
10/14/06	674.1716667
10/15/06	668.8945833
10/16/06	672.7229167
10/17/06	681.9033333
10/18/06	684.62
10/19/06	821.32125
10/20/06	894.4979167
10/21/06	868.82
10/22/06	855.36125
10/23/06	975.1991667
10/24/06	1085.498333
10/25/06	1119.410417
10/26/06	1304.517917
10/27/06	1563.75125
10/28/06	2144.124583
10/29/06	2495.385
10/30/06	2502.007083
10/31/06	2507.125417
11/1/06	2507.555
11/2/06	1308.57375
11/3/06	1063.14625
11/4/06	656.1133333
11/5/06	671.6741667
11/6/06	678.07125
11/7/06	672.07375
11/8/06	1239.339167
11/9/06	2262.2225

Date	Flow (cfs)
11/10/06	1973.639583
11/11/06	1784.541667
11/12/06	1312.72625
11/13/06	1288.177917
11/14/06	1215.789583
11/15/06	1738.483333
11/16/06	6495.338333
11/17/06	12024.95833
11/18/06	6696.697917
11/19/06	2446.421667
11/20/06	1918.209583
11/21/06	1769.05625
11/22/06	1658.592083
11/23/06	4349.5825
11/24/06	3556.80125
11/25/06	1768.262917
11/26/06	1693.81625
11/27/06	1699.39875
11/28/06	1671.279583
11/29/06	1571.635417
11/30/06	1421.0925
12/1/06	1099.830417
12/2/06	1084.74875
12/3/06	940.0591667
12/4/06	873.3670833
12/5/06	889.6858333
12/6/06	725.6875
12/7/06	665.24375
12/8/06	667.6820833
12/9/06	674.3279167
12/10/06	667.4225
12/11/06	665.74125
12/12/06	667.9870833
12/13/06	668.13875
12/14/06	658.8433333
12/15/06	647.9379167
12/16/06	668.8404167
12/17/06	677.18875
12/18/06	682.1958333
12/19/06	685.4704167
12/20/06	840.6241667
12/21/06	1333.955417
12/22/06	1849.360417
12/23/06	1839.991667
12/24/06	1467.100417
12/25/06	1346.27625
12/26/06	2349.76125

Date	Flow (cfs)
12/27/06	2548.4825
12/28/06	1829.8175
12/29/06	1505.304583
12/30/06	1498.946667
12/31/06	1274.620833
1/1/07	5039.558333
1/2/07	9080.79375
1/3/07	3861.014583
1/4/07	1902.285
1/5/07	1948.965833
1/6/07	2371.300417
1/7/07	2152.2975
1/8/07	4121.97875
1/9/07	4645.67875
1/10/07	4646.955417
1/11/07	2758.369167
1/12/07	1918.292917
1/13/07	1581.643333
1/14/07	1443.01625
1/15/07	1403.914167
1/16/07	1264.835417
1/17/07	1093.368333
1/18/07	1039.309167
1/19/07	1042.317083
1/20/07	1036.900417
1/21/07	1034.245
1/22/07	1157.884167
1/23/07	1172.85
1/24/07	1189.669583
1/25/07	1184.092917
1/26/07	1186.115
1/27/07	1174.929167
1/28/07	1155.49375
1/29/07	1189.732917
1/30/07	1042.477917
1/31/07	893.6075
2/1/07	889.7925
2/2/07	1130.996667
2/3/07	649.8479167
2/4/07	640.2758333
2/5/07	661.7858333
2/6/07	673.51375
2/7/07	673.7045833
2/8/07	1051.282917
2/9/07	653.5116667
2/10/07	646.1154167
2/11/07	633.7358333

Date	Flow (cfs)
2/12/07	632.8158333
2/13/07	778.8533333
2/14/07	4175.045417
2/15/07	4707.519167
2/16/07	2922.684167
2/17/07	2093.867917
2/18/07	1797.41125
2/19/07	1370.92125
2/20/07	1096.436667
2/21/07	1086.650417
2/22/07	1174.125
2/23/07	1464.50875
2/24/07	1535.059167
2/25/07	1310.207083
2/26/07	1300.709167
2/27/07	1356.515833
2/28/07	1352.197083
3/1/07	1729.268333
3/2/07	4180.222083
3/3/07	4618.772083
3/4/07	3230.820417
3/5/07	1943.869167
3/6/07	1658.144167
3/7/07	1624.82125
3/8/07	1221.289583
3/9/07	1092.02625
3/10/07	1091.824167
3/11/07	1003.825417
3/12/07	905.3375
3/13/07	910.1354167
3/14/07	914.1275
3/15/07	1313.024167
3/16/07	7012.300417
3/17/07	9413.1225
3/18/07	8428.346667
3/19/07	3676.707917
3/20/07	2246.182083
3/21/07	1870.634583
3/22/07	1790.629167
3/23/07	1572.757083
3/24/07	1387.31
3/25/07	1293.7425
3/26/07	1202.1775
3/27/07	1205.43
3/28/07	1364.342917
3/29/07	2079.632083
3/30/07	2023.865833

Date	Flow (cfs)
3/31/07	1534.755833
4/1/07	1502.04125
4/2/07	1502.515833
4/3/07	1353.574167
4/4/07	1035.255833
4/5/07	896.2616667
4/6/07	826.2075
4/7/07	829.2791667
4/8/07	823.7095833
4/9/07	851.0179167
4/10/07	869.565
4/11/07	977.0491667
4/12/07	1872.422083
4/13/07	4126.079167
4/14/07	4228.521667
4/15/07	1962.176667
4/16/07	4378.935833
4/17/07	3985.550833
4/18/07	2590.63
4/19/07	1953.240417
4/20/07	1470.755417
4/21/07	1160.83
4/22/07	1188.850833
4/23/07	1169.40375
4/24/07	772.61875
4/25/07	1059.002917
4/26/07	1287.16125
4/27/07	1400.113333
4/28/07	1429.570417
4/29/07	1522.314583
4/30/07	1296.8025
5/1/07	893.88625
5/2/07	748.3725
5/3/07	913.2879167
5/4/07	1392.915417
5/5/07	1428.557917
5/6/07	1528.677917
5/7/07	1616.760833
5/8/07	1211.096667
5/9/07	952.8608333
5/10/07	954.955
5/11/07	950.2383333
5/12/07	951.6745833
5/13/07	1208.327917
5/14/07	1396.314583
5/15/07	866.8991667
5/16/07	718.0708333

Date	Flow (cfs)
5/17/07	713.0179167
5/18/07	717.6358333
5/19/07	718.0091667
5/20/07	705.35625
5/21/07	718.2508333
5/22/07	724.7645833
5/23/07	722.84
5/24/07	725.1883333
5/25/07	720.1125
5/26/07	715.1891667
5/27/07	708.1558333
5/28/07	710.05375
5/29/07	672.57875
5/30/07	683.8583333
5/31/07	680.2795833
6/1/07	731.8054167
6/2/07	957.7570833
6/3/07	1483.01
6/4/07	2275.266667
6/5/07	2143.19125
6/6/07	947.2633333
6/7/07	752.8525
6/8/07	660.4079167
6/9/07	665.3925
6/10/07	663.59875
6/11/07	662.3470833
6/12/07	670.7366667
6/13/07	670.40875
6/14/07	668.9279167
6/15/07	666.7633333
6/16/07	666.9870833
6/17/07	666.2145833
6/18/07	666.6220833
6/19/07	667.5291667
6/20/07	668.385
6/21/07	670.4841667
6/22/07	665.405
6/23/07	675.7408333
6/24/07	668.6979167
6/25/07	665.1866667
6/26/07	665.52125
6/27/07	675.335
6/28/07	673.75625
6/29/07	677.9695833
6/30/07	674.8554167
7/1/07	676.4504167
7/2/07	694.0845833

Date	Flow (cfs)
7/3/07	679.6554167
7/4/07	661.97625
7/5/07	658.89375
7/6/07	654.6583333
7/7/07	665.5858333
7/8/07	656.2404167
7/9/07	664.90125
7/10/07	671.6620833
7/11/07	672.2754167
7/12/07	669.8275
7/13/07	660.7604167
7/14/07	656.5504167
7/15/07	666.0991667
7/16/07	667.6904167
7/17/07	666.1933333
7/18/07	672.3625
7/19/07	680.2495833
7/20/07	669.6658333
7/21/07	667.7641667
7/22/07	664.2083333
7/23/07	664.95
7/24/07	636.2016667
7/25/07	661.61
7/26/07	663.9566667
7/27/07	665.01875
7/28/07	664.7895833
7/29/07	663.5083333
7/30/07	655.5475
7/31/07	667.1808333
8/1/07	663.1679167
8/2/07	662.0595833
8/3/07	666.1875
8/4/07	670.0466667
8/5/07	668.37
8/6/07	668.4533333
8/7/07	654.975
8/8/07	654.7245833
8/9/07	653.2920833
8/10/07	654.7529167
8/11/07	652.7141667
8/12/07	650.3570833
8/13/07	656.18
8/14/07	658.6583333
8/15/07	714.7595833
8/16/07	574.43625
8/17/07	575.7866667
8/18/07	656.9729167

Date	Flow (cfs)
8/19/07	516.0433333
8/20/07	505.4454167
8/21/07	502.2308333
8/22/07	500.64625
8/23/07	503.2708333
8/24/07	581.4475
8/25/07	659.7220833
8/26/07	515.4866667
8/27/07	507.86625
8/28/07	512.64625
8/29/07	509.0033333
8/30/07	500.6445833
8/31/07	592.2245833
9/1/07	651.64
9/2/07	631.5533333
9/3/07	494.3225
9/4/07	505.6558333
9/5/07	560.9670833
9/6/07	539.8220833
9/7/07	590.4954167
9/8/07	639.8883333
9/9/07	501.4866667
9/10/07	502.1733333
9/11/07	500.45
9/12/07	565.44125
9/13/07	499.5008333
9/14/07	588.2045833
9/15/07	639.94625
9/16/07	504.6854167
9/17/07	511.7466667
9/18/07	506.54375
9/19/07	503.22375
9/20/07	504.475
9/21/07	588.5883333
9/22/07	666.3133333
9/23/07	504.8066667
9/24/07	399.26125
9/25/07	400.6920833
9/26/07	401.6266667
9/27/07	402.5804167
9/28/07	559.0866667
9/29/07	591.4829167
9/30/07	400.8575
10/1/07	399.5879167
10/2/07	403.4708333
10/3/07	404.1591667
10/4/07	399.8558333

Date	Flow (cfs)
10/5/07	553.2029167
10/6/07	650.4508333
10/7/07	405.1545833
10/8/07	402.81375
10/9/07	402.4670833
10/10/07	405.1858333
10/11/07	399.0204167
10/12/07	533.1941667
10/13/07	402.6241667
10/14/07	402.6895833
10/15/07	401.6208333
10/16/07	402.4758333
10/17/07	405.38125
10/18/07	405.8733333
10/19/07	532.27
10/20/07	404.7016667
10/21/07	401.38125
10/22/07	400.5066667
10/23/07	403.9791667
10/24/07	408.435
10/25/07	400.29
10/26/07	400.7475
10/27/07	402.33875
10/28/07	401.5479167
10/29/07	467.20375
10/30/07	411.3454167
10/31/07	410.72125
11/1/07	404.0183333
11/2/07	402.2691667
11/3/07	401.4166667
11/4/07	401.7191667
11/5/07	401.62125
11/6/07	402.4625
11/7/07	403.3825
11/8/07	402.5133333
11/9/07	400.79875
11/10/07	398.4920833
11/11/07	401.2658333
11/12/07	400.7175
11/13/07	402.7979167
11/14/07	403.73125
11/15/07	401.0975
11/16/07	401.8191667
11/17/07	400.40375
11/18/07	397.9025
11/19/07	404.5616667
11/20/07	404.4329167

Date	Flow (cfs)
11/21/07	402.5545833
11/22/07	402.2054167
11/23/07	399.5766667
11/24/07	401.05375
11/25/07	400.8304167
11/26/07	398.5429167
11/27/07	404.89625
11/28/07	406.4416667
11/29/07	405.0204167
11/30/07	401.2125
12/1/07	400.87625
12/2/07	400.6683333
12/3/07	399.8520833
12/4/07	401.5016667
12/5/07	400.0475
12/6/07	401.8729167
12/7/07	404.1966667
12/8/07	405.46875
12/9/07	404.1125
12/10/07	404.9716667
12/11/07	403.2533333
12/12/07	403.9583333
12/13/07	404.6666667
12/14/07	401.9858333
12/15/07	418.2733333
12/16/07	416.2204167
12/17/07	401.9004167
12/18/07	401.4679167
12/19/07	403.5804167
12/20/07	374.6841667
12/21/07	353.2691667
12/22/07	351.83625
12/23/07	355.3279167
12/24/07	353.25125
12/25/07	355.30625
12/26/07	351.7675
12/27/07	351.5308333
12/28/07	350.855
12/29/07	352.44125
12/30/07	352.7858333
12/31/07	355.4604167
1/1/08	356.4458333
1/2/08	352.6583333
1/3/08	354.4804167
1/4/08	352.16125
1/5/08	350.85875
1/6/08	350.8295833

Date	Flow (cfs)
1/7/08	352.02125
1/8/08	353.0833333
1/9/08	351.3791667
1/10/08	354.1054167
1/11/08	355.9191667
1/12/08	350.4979167
1/13/08	351.91
1/14/08	353.8095833
1/15/08	351.9291667
1/16/08	357.4795833
1/17/08	353.3720833
1/18/08	355.6704167
1/19/08	350.2008333
1/20/08	371.3958333
1/21/08	355.8575
1/22/08	354.66625
1/23/08	355.3070833
1/24/08	354.97125
1/25/08	357.9066667
1/26/08	353.3970833
1/27/08	353.6095833
1/28/08	355.4425
1/29/08	352.71125
1/30/08	351.7208333
1/31/08	353.9991667
2/1/08	353.6375
2/2/08	356.1166667
2/3/08	378.3679167
2/4/08	363.3625
2/5/08	352.2525
2/6/08	354.6633333
2/7/08	358.09375
2/8/08	355.8920833
2/9/08	351.3941667
2/10/08	419.48625
2/11/08	359.2954167
2/12/08	359.0804167
2/13/08	349.55
2/14/08	407.3541667
2/15/08	355.9925
2/16/08	366.225
2/17/08	349.7054167
2/18/08	349.2754167
2/19/08	354.075
2/20/08	351.8783333
2/21/08	469.9191667
2/22/08	551.8279167

Date	Flow (cfs)
2/23/08	550.87875
2/24/08	555.5883333
2/25/08	551.3454167
2/26/08	555.16
2/27/08	550.6195833
2/28/08	550.7329167
2/29/08	550.8875
3/1/08	551.2108333
3/2/08	554.11375
3/3/08	554.725
3/4/08	552.8820833
3/5/08	555.4954167
3/6/08	560.0091667
3/7/08	573.4383333
3/8/08	788.28125
3/9/08	1274.779583
3/10/08	1336.769167
3/11/08	993.0604167
3/12/08	964.62625
3/13/08	849.8145833
3/14/08	770.96375
3/15/08	745.3870833
3/16/08	1943.50375
3/17/08	902.8579167
3/18/08	675.2875
3/19/08	676.1295833
3/20/08	666.0033333
3/21/08	681.9766667
3/22/08	679.3095833
3/23/08	677.7541667
3/24/08	669.1529167
3/25/08	660.6166667
3/26/08	654.5041667
3/27/08	651.4504167
3/28/08	644.54875
3/29/08	662.42625
3/30/08	654.2654167
3/31/08	653.2775
4/1/08	652.95875
4/2/08	656.11875
4/3/08	654.37375
4/4/08	648.47
4/5/08	650.4458333
4/6/08	1135.67125
4/7/08	4311.125833
4/8/08	4399.177083
4/9/08	1858.53625

Date	Flow (cfs)
4/10/08	1299.3625
4/11/08	980.15
4/12/08	911.4425
4/13/08	1514.6625
4/14/08	1917.457083
4/15/08	1004.648333
4/16/08	965.3270833
4/17/08	672.34375
4/18/08	710.19
4/19/08	721.255
4/20/08	981.72125
4/21/08	1127.110417
4/22/08	1137.215
4/23/08	1141.897083
4/24/08	1139.918333
4/25/08	1106.746667
4/26/08	1063.22625
4/27/08	1114.247917
4/28/08	3194.7725
4/29/08	4549.917083
4/30/08	4529.618333
5/1/08	2246.005833
5/2/08	1632.415417
5/3/08	1660.67625
5/4/08	1400.894583
5/5/08	1237.483333
5/6/08	833.9233333
5/7/08	726.4604167
5/8/08	731.3129167
5/9/08	1511.619583
5/10/08	2202.998333
5/11/08	2434.027083
5/12/08	2738.457083
5/13/08	1810.307917
5/14/08	1166.270833
5/15/08	902.7016667
5/16/08	830.6541667
5/17/08	830.4979167
5/18/08	1171.4475
5/19/08	1190.210833
5/20/08	834.4870833
5/21/08	667.2520833
5/22/08	676.47125
5/23/08	713.6575
5/24/08	723.1541667
5/25/08	1223.765833
5/26/08	1327.880417

Appendix E:
Roanoke River PCB TMDL Model Hydrologic Calibration and Validation Results

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LIST OF FIGURES

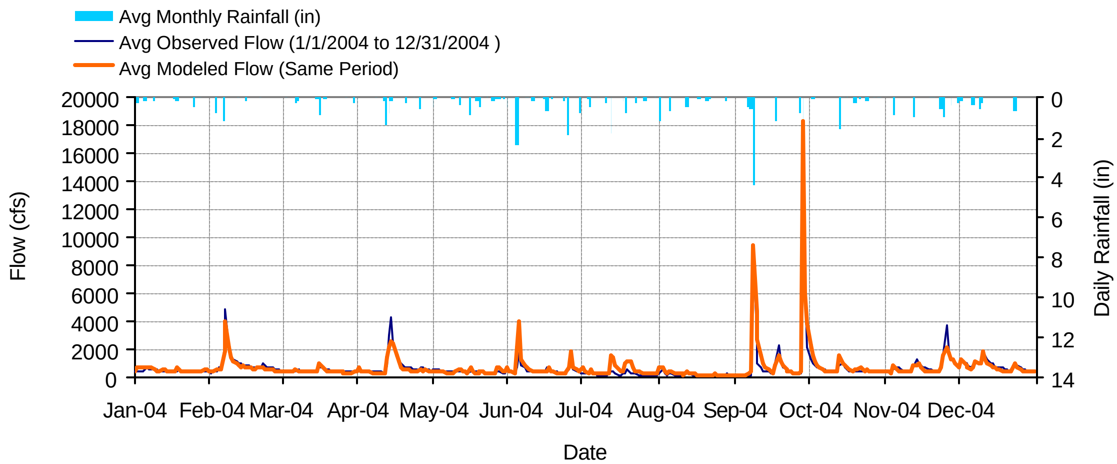

Figure E-1. Calibration mean daily flow: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

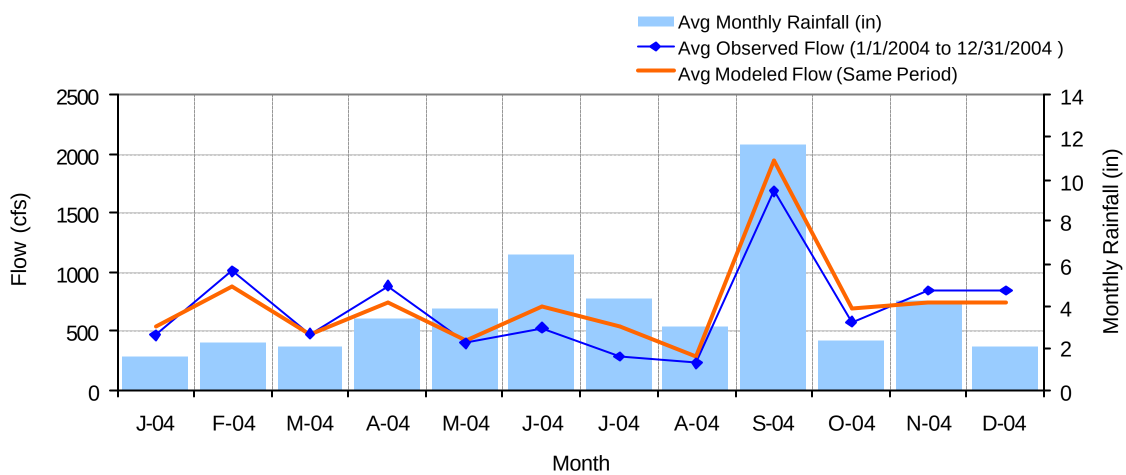

Figure E-2. Calibration mean monthly flow: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

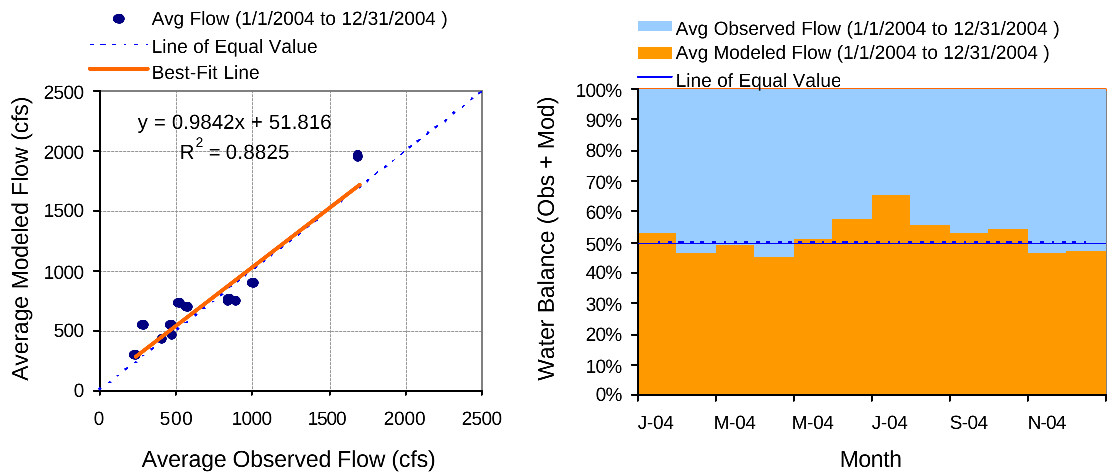

Figure E-3. Calibration monthly flow regression and temporal variation: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

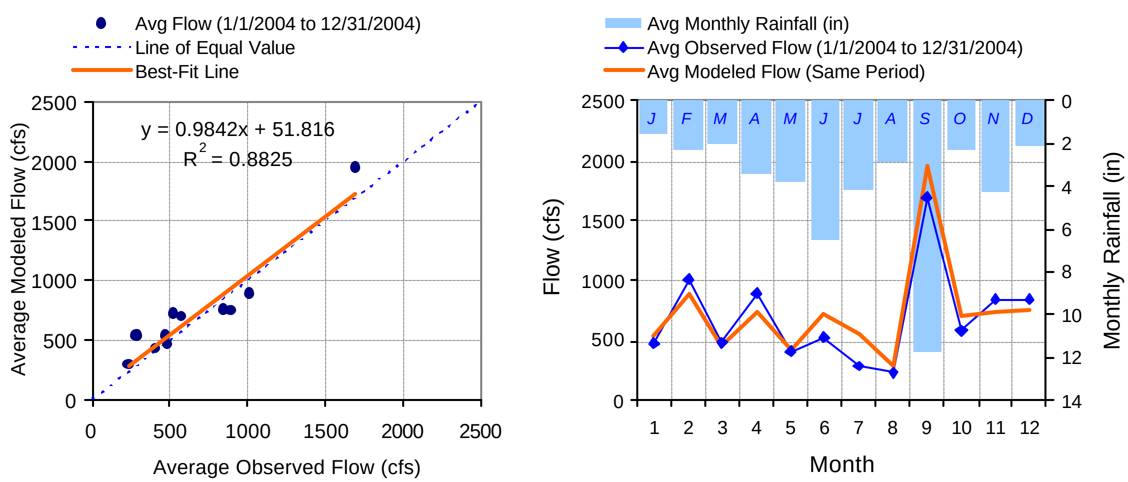

Figure E-4. Calibration seasonal regression and temporal aggregate: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

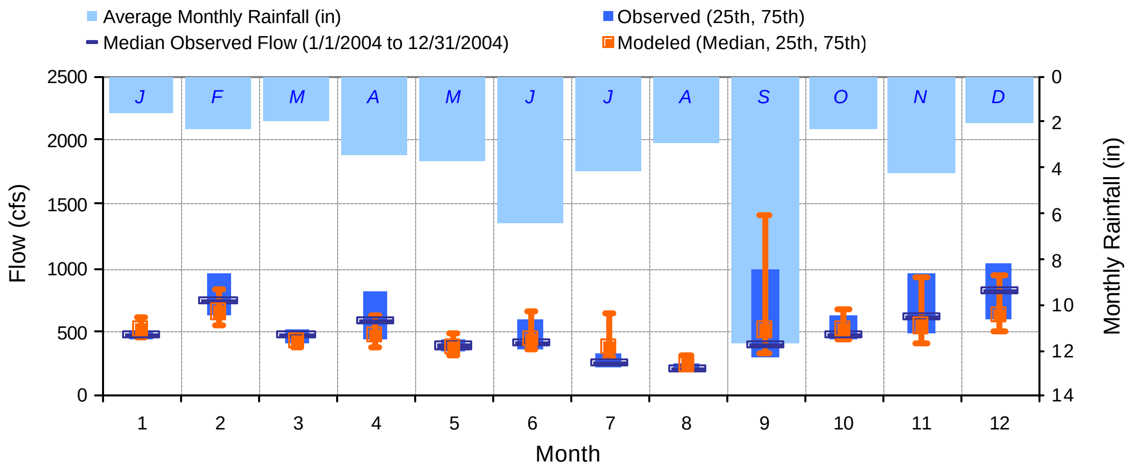

Figure E-5. Calibration seasonal medians and ranges: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

Table E-1. Calibration seasonal summary: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Jan	475.61	480.00	438.50	511.00	540.57	522.03	460.34	610.33
Feb	1011.31	743.00	629.00	951.00	889.86	657.34	548.73	834.01
Mar	480.68	473.00	412.50	516.50	462.43	432.38	388.77	474.82
Apr	890.03	590.50	431.25	810.50	741.13	470.22	374.46	624.69
May	407.71	394.00	350.00	439.00	427.55	379.49	320.53	490.96
Jun	526.97	421.50	368.25	590.50	720.11	455.63	362.42	662.06
Jul	285.03	255.00	230.50	328.00	547.17	377.60	296.07	647.38
Aug	235.29	210.00	194.00	254.00	290.93	246.75	206.80	324.29
Sep	1693.17	396.00	302.50	993.00	1953.82	519.04	330.14	1415.32
Oct	579.97	478.00	436.00	621.00	693.34	529.02	440.99	682.23
Nov	845.80	612.50	494.75	948.00	746.19	551.11	412.13	918.73
Dec	846.52	818.00	597.50	1035.00	756.26	636.06	499.64	946.05

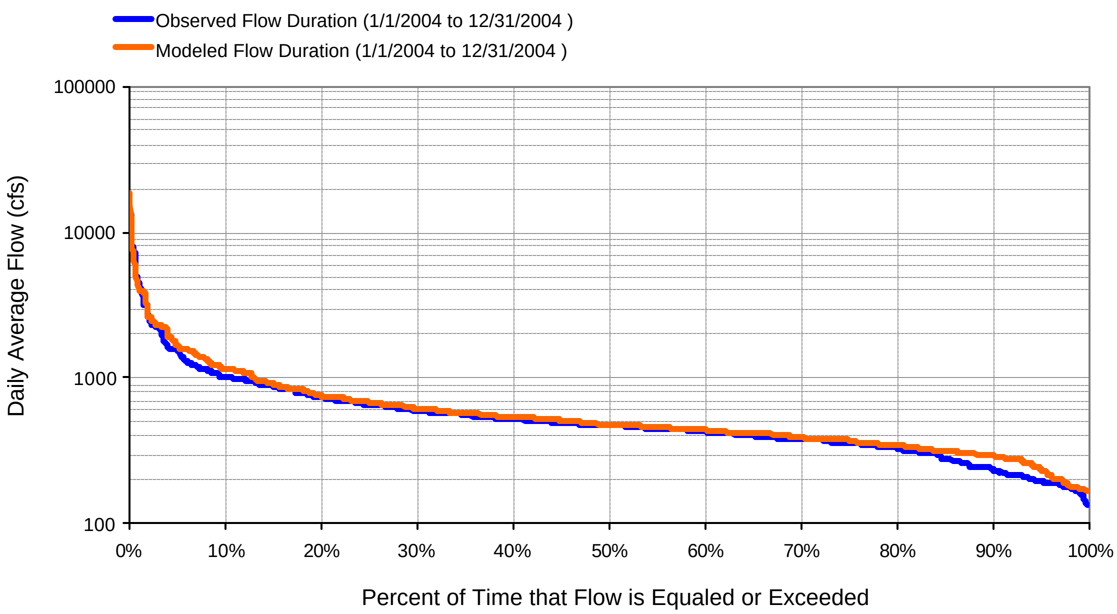

Figure E-6. Calibration flow exceedence: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

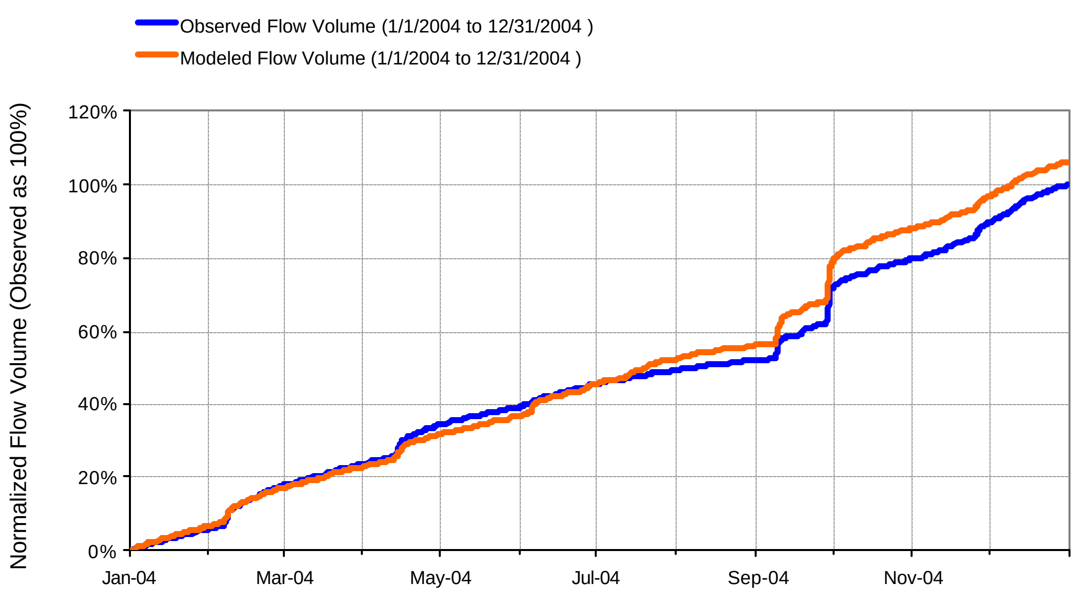

Figure E-7. Calibration flow accumulation: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

Table E-2. Calibration summary statistics: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

LSPC Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM SUBBASIN 3011		USGS 02056000 ROANOKE RIVER AT NIAGARA, VA	
1-Year Analysis Period: 1/1/2004 - 12/31/2004 Flow volumes are (inches/year) for upstream drainage area		Hydrologic Unit Code: 3010101 Latitude: 37.2551384 Longitude: -79.87142539 Drainage Area (sq-mi): 509	
Total Simulated In-stream Flow:	**19.39**	Total Observed In-stream Flow:	**18.28**
Total of simulated highest 10% flows:	**7.49**	Total of Observed highest 10% flows:	**6.98**
Total of Simulated lowest 50% flows:	**4.83**	Total of Observed Lowest 50% flows:	**4.55**
Simulated Summer Flow Volume (months 7-9):	**6.17**	Observed Summer Flow Volume (7-9):	**4.88**
Simulated Fall Flow Volume (months 10-12):	**4.91**	Observed Fall Flow Volume (10-12):	**5.07**
Simulated Winter Flow Volume (months 1-3):	**4.15**	Observed Winter Flow Volume (1-3):	**4.30**
Simulated Spring Flow Volume (months 4-6):	**4.16**	Observed Spring Flow Volume (4-6):	**4.02**
Total Simulated Storm Volume:	**8.51**	Total Observed Storm Volume:	**7.12**
Simulated Summer Storm Volume (7-9)	**4.17**	Observed Summer Storm Volume (7-9):	**3.32**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*1995-1999*	*2000-2004*
Error in total volume:	6.09	10	-1.43	7.35
Error in 50% lowest flows:	6.26	10	-1.60	-3.91
Error in 10% highest flows:	7.40	15	2.26	1.75
Seasonal volume error - Summer:	26.40	30	13.27	-2.52
Seasonal volume error - Fall:	-3.26	30	4.49	12.42
Seasonal volume error - Winter:	-3.52	30	-18.21	13.31
Seasonal volume error - Spring:	3.52	30	1.90	6.11
Error in storm volumes:	19.46	20	1.13	12.07
Error in summer storm volumes:	25.70	50	3.16	15.42
Nash-Sutcliffe Coefficient of Efficiency, E:	0.917	Model accuracy increases	0.688	0.814
Baseline adjusted coefficient (Garrick), E':	0.620	as E or E' approaches 1.0	0.517	0.549

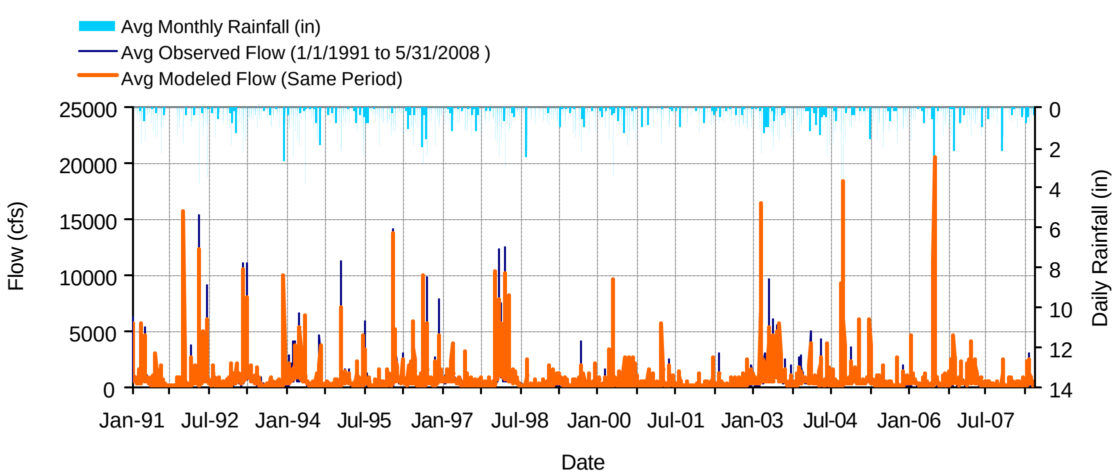

Figure E-8. Validation mean daily flow: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

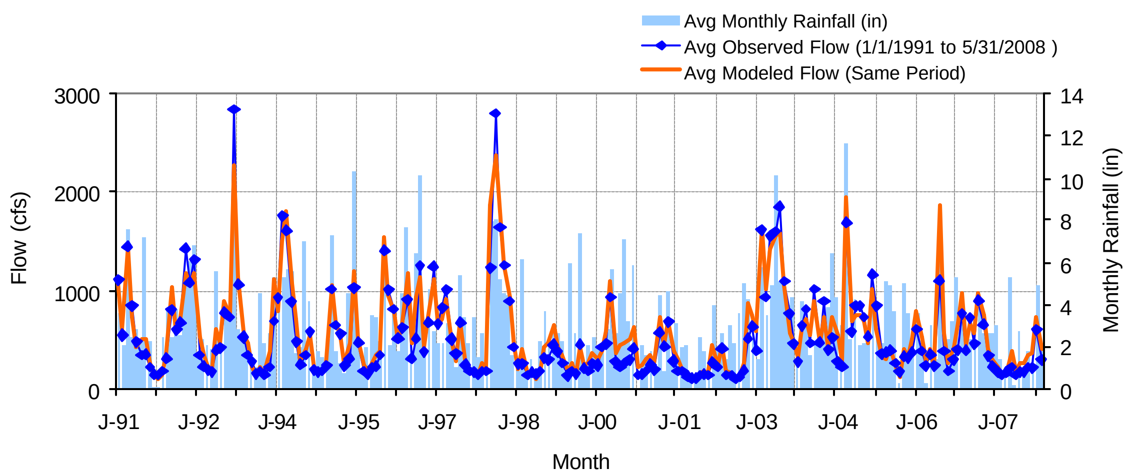

Figure E-9. Validation mean monthly flow: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

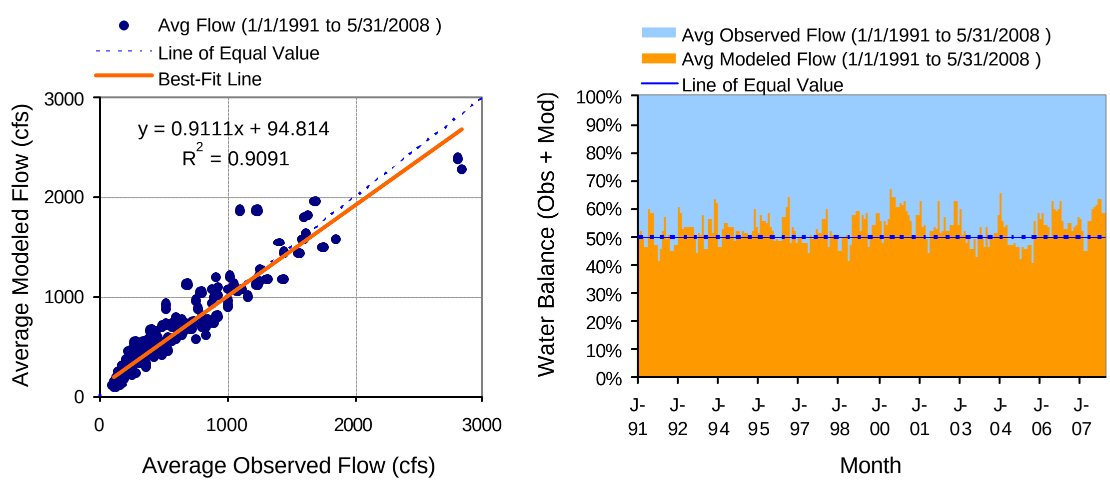

Figure E-10. Validation monthly flow regression and temporal variation: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

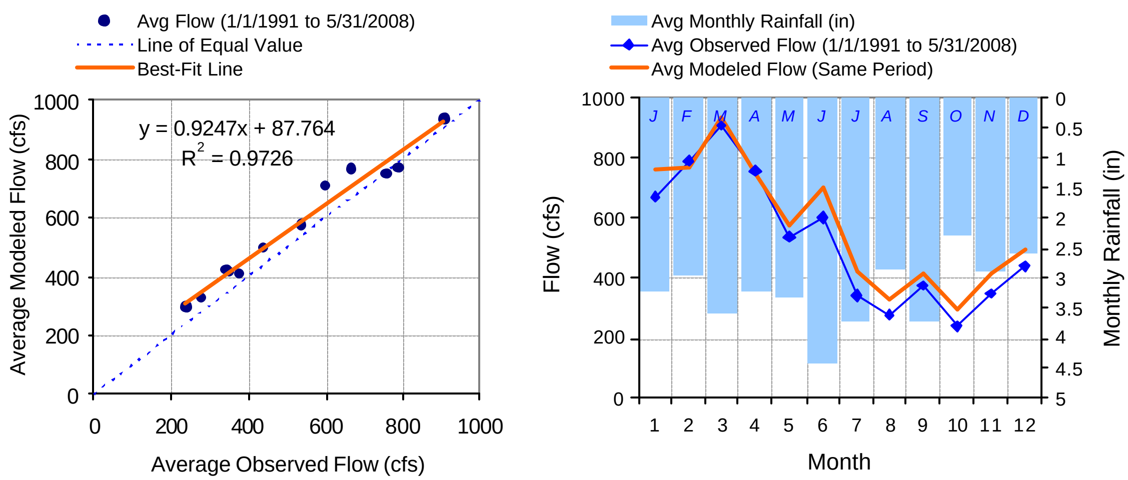

Figure E-11. Validation seasonal regression and temporal aggregate: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

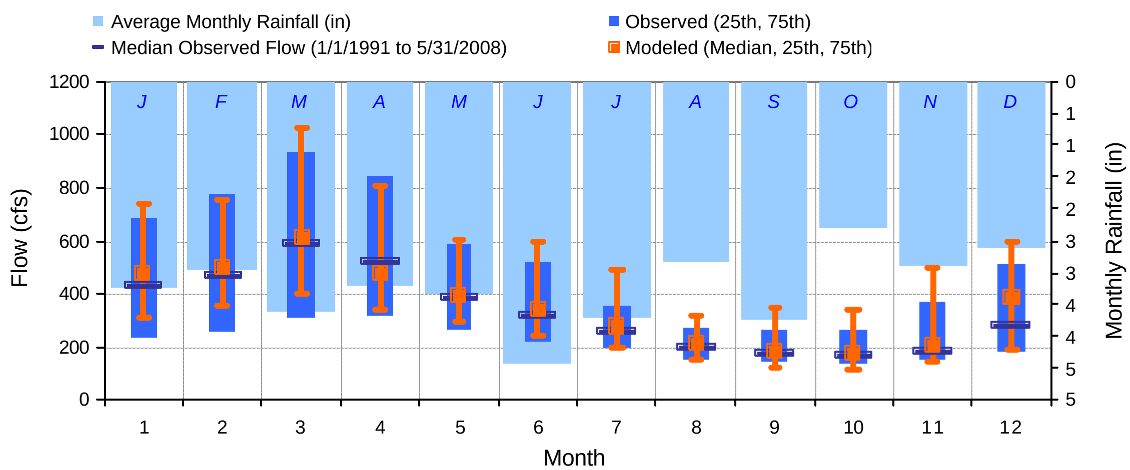

Figure E-12. Validation seasonal medians and ranges: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

Table E-3. Validation seasonal summary: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Jan	668.21	434.00	237.25	683.75	763.41	473.11	312.12	736.08
Feb	789.55	471.00	256.00	778.00	768.08	498.60	358.37	755.82
Mar	906.11	590.00	305.50	931.50	935.42	609.58	398.10	1022.25
Apr	758.49	522.00	317.00	842.00	748.16	479.30	338.95	805.00
May	537.77	384.00	264.00	588.75	572.82	393.90	288.36	603.89
Jun	600.41	319.50	219.00	517.00	704.41	340.38	245.17	590.83
Jul	340.59	255.00	195.50	349.50	421.96	278.05	195.38	494.41
Aug	274.89	198.00	153.00	270.50	325.77	214.38	146.08	316.00
Sep	376.06	178.00	144.00	267.00	410.57	183.82	121.09	345.95
Oct	237.68	170.00	137.00	260.00	296.43	178.13	112.68	334.07
Nov	348.15	188.00	152.25	372.75	415.39	205.13	144.15	497.82
Dec	438.82	281.00	179.50	512.00	494.98	384.18	190.23	595.31

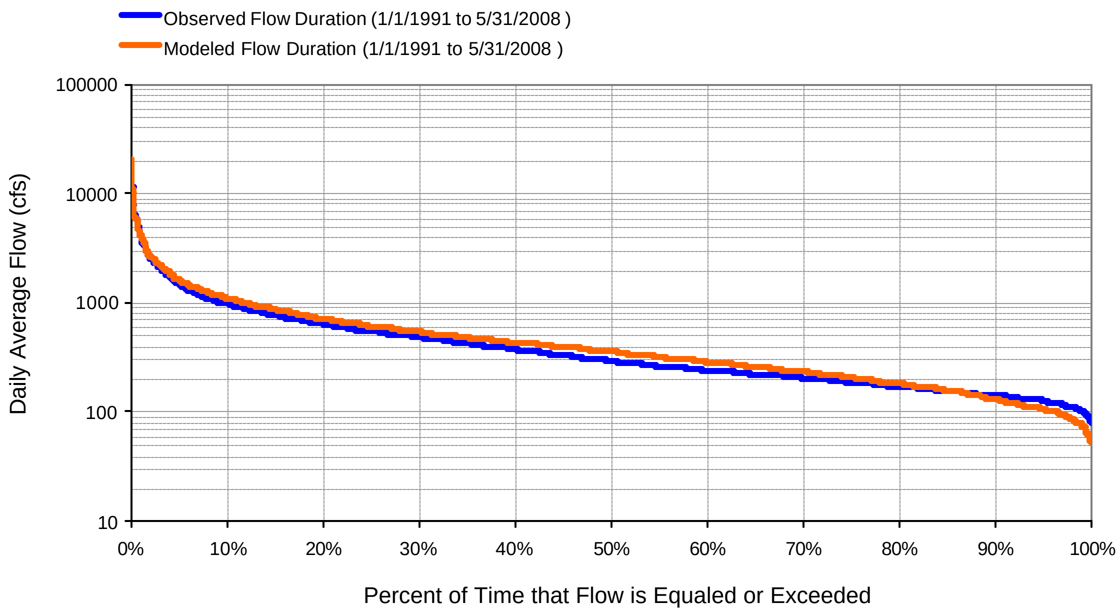

Figure E-13. Validation flow exceedence: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

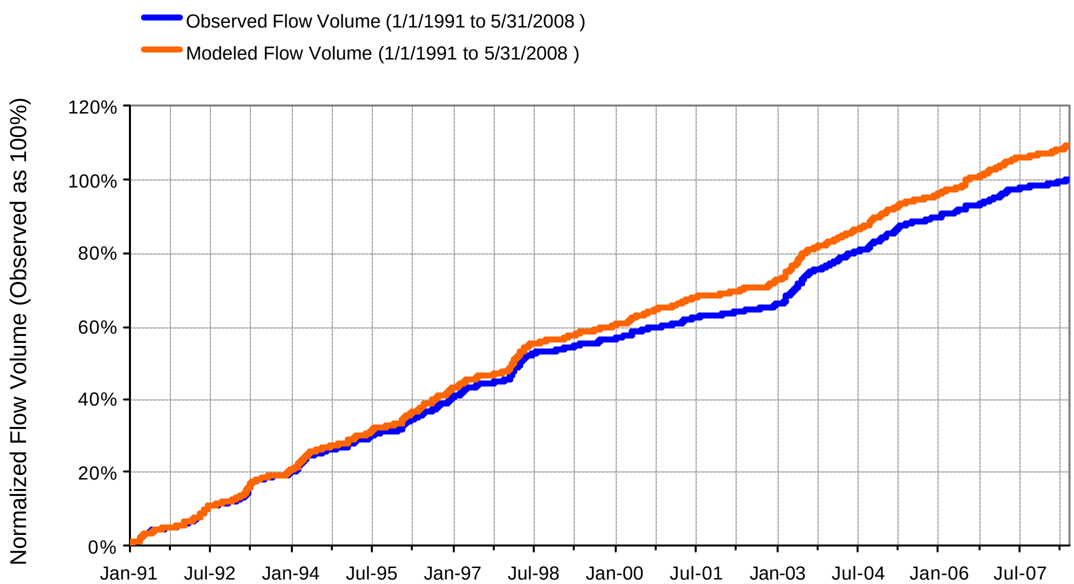

Figure E-14. Validation flow accumulation: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

Table E-4. Validation summary statistics: Model Outlet 3011 vs. USGS 02056000 Roanoke River At Niagara, VA

LSPC Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM SUBBASIN 3011 17.42-Year Analysis Period: 1/1/1991 - 5/31/2008 Flow volumes are (inches/year) for upstream drainage area		USGS 02056000 ROANOKE RIVER AT NIAGARA, VA Hydrologic Unit Code: 3010101 Latitude: 37.2551384 Longitude: -79.87142539 Drainage Area (sq-mi): 509		
Total Simulated In-stream Flow:	**15.33**	Total Observed In-stream Flow:		**14.04**
Total of simulated highest 10% flows:	**6.20**	Total of Observed highest 10% flows:		**5.92**
Total of Simulated lowest 50% flows:	**2.79**	Total of Observed Lowest 50% flows:		**2.54**
Simulated Summer Flow Volume (months 7-9):	**2.53**	Observed Summer Flow Volume (7-9):		**2.17**
Simulated Fall Flow Volume (months 10-12):	**2.64**	Observed Fall Flow Volume (10-12):		**2.24**
Simulated Winter Flow Volume (months 1-3):	**5.62**	Observed Winter Flow Volume (1-3):		**5.37**
Simulated Spring Flow Volume (months 4-6):	**4.54**	Observed Spring Flow Volume (4-6):		**4.26**
Total Simulated Storm Volume:	**6.12**	Total Observed Storm Volume:		**5.20**
Simulated Summer Storm Volume (7-9)	**1.07**	Observed Summer Storm Volume (7-9):		**0.79**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*1995-1999*	*2000-2004*
Error in total volume:	9.19	10	-1.43	7.35
Error in 50% lowest flows:	9.78	10	-1.60	-3.91
Error in 10% highest flows:	4.76	15	2.26	1.75
Seasonal volume error - Summer:	16.91	30	13.27	-2.52
Seasonal volume error - Fall:	17.76	30	4.49	12.42
Seasonal volume error - Winter:	4.57	30	-18.21	13.31
Seasonal volume error - Spring:	6.60	30	1.90	6.11
Error in storm volumes:	17.66	20	1.13	12.07
Error in summer storm volumes:	35.02	50	3.16	15.42
Nash-Sutcliffe Coefficient of Efficiency, E:	0.799	Model accuracy increases	0.688	0.814
Baseline adjusted coefficient (Garrick), E':	0.607	as E or E' approaches 1.0	0.517	0.549

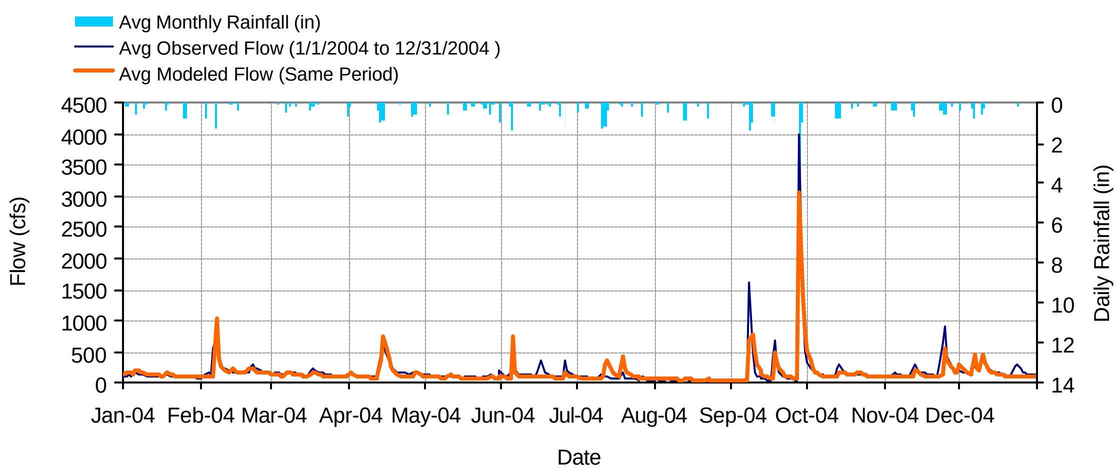

Figure E-15. Calibration mean daily flow: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

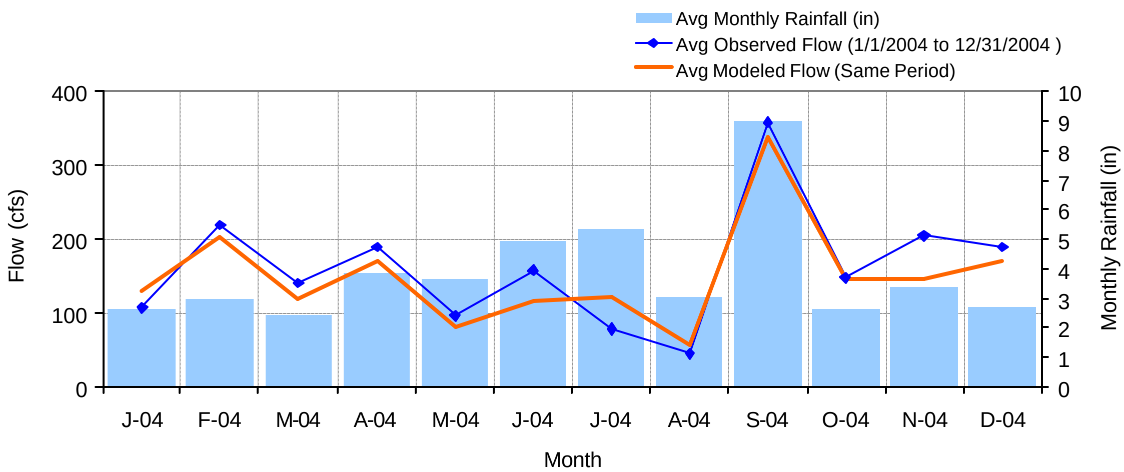

Figure E-16. Calibration mean monthly flow: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

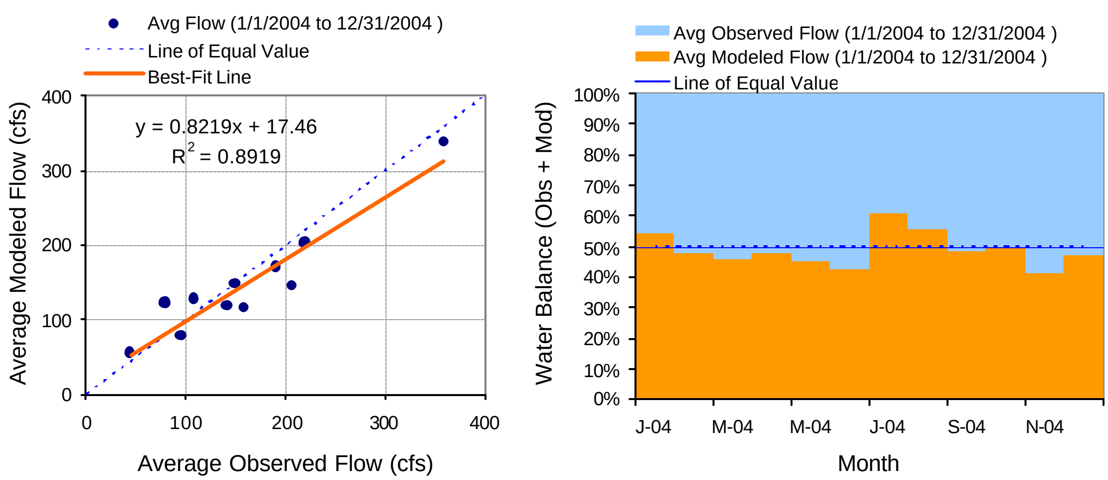

Figure E-17. Calibration monthly flow regression and temporal variation: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

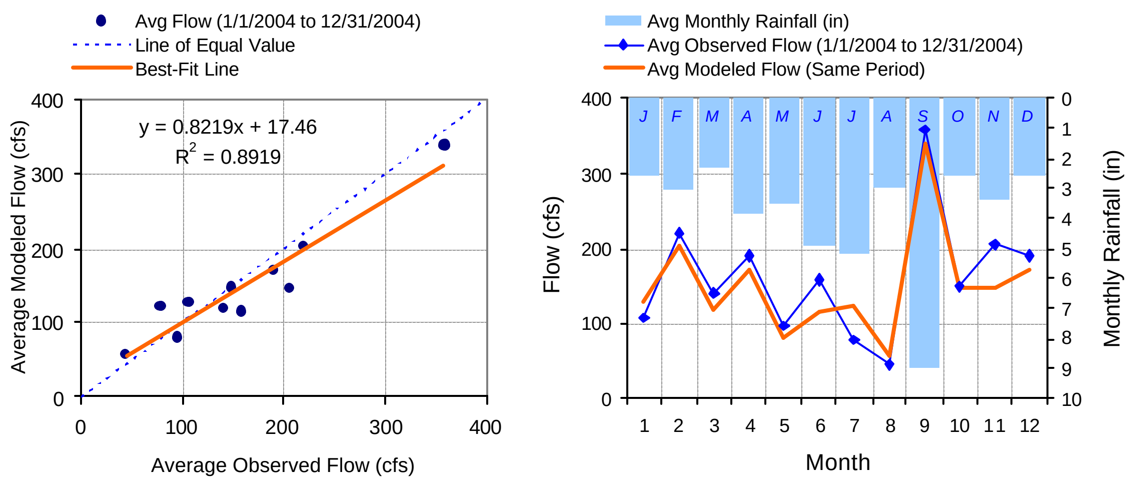

Figure E-18. Calibration seasonal regression and temporal aggregate: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

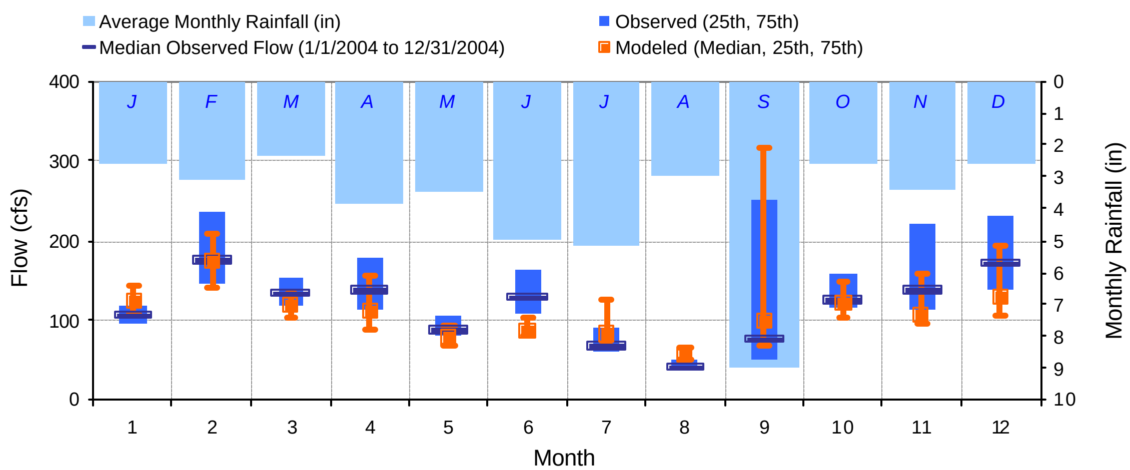

Figure E-19. Calibration seasonal medians and ranges: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

Table E-5. Calibration Seasonal summary: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Jan	107.06	106.00	94.50	117.50	128.56	124.94	107.52	141.49
Feb	219.59	176.00	145.00	235.00	203.67	173.29	141.45	207.55
Mar	140.61	135.00	117.50	153.00	118.60	118.72	102.43	133.27
Apr	190.37	137.00	112.00	177.50	171.76	110.53	89.04	155.41
May	95.94	88.00	81.00	105.50	80.43	76.52	68.40	91.19
Jun	158.17	128.50	108.00	163.75	115.71	86.55	79.90	102.90
Jul	78.42	68.00	59.50	89.50	122.75	82.29	67.99	125.51
Aug	44.65	42.00	37.00	50.00	57.07	56.63	50.68	64.58
Sep	358.27	76.00	50.50	251.50	338.37	98.18	68.93	316.87
Oct	149.03	125.00	115.00	158.00	147.99	121.29	103.90	149.11
Nov	205.37	137.00	113.50	222.25	146.55	106.16	94.45	157.21
Dec	190.23	171.00	138.50	230.00	170.59	128.54	104.71	193.55

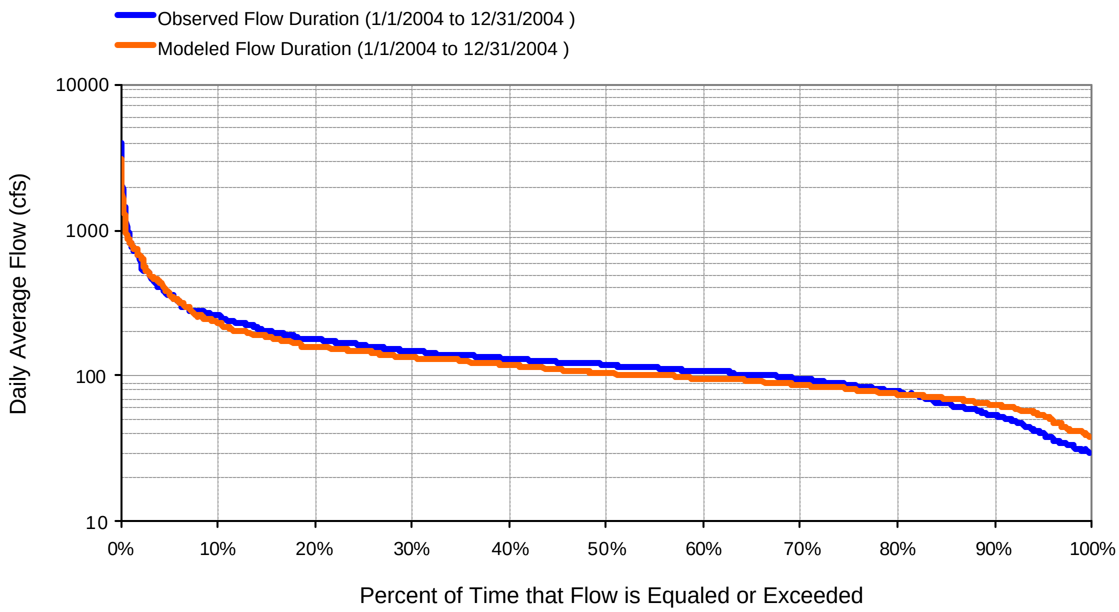

Figure E-20. Calibration flow exceedence: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

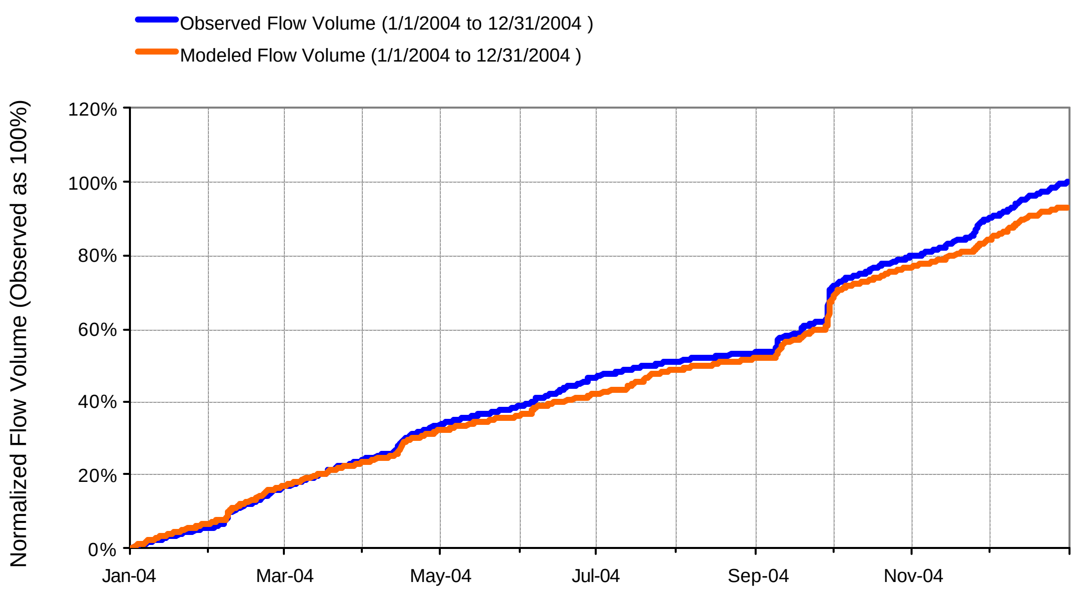

Figure E-21. Calibration flow accumulation: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

Table E-6. Calibration summary statistics: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

LSPC Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM SUBBASIN 3029 1-Year Analysis Period: 1/1/2004 - 12/31/2004 Flow volumes are (inches/year) for upstream drainage area		USGS 02053800 S F ROANOKE RIVER NEAR SHAWSVILLE, VA Hydrologic Unit Code: 3010101 Latitude: 37.1401323 Longitude: -80.2664328 Drainage Area (sq-mi): 109		
Total Simulated In-stream Flow:	**18.62**	Total Observed In-stream Flow:		**19.99**
Total of simulated highest 10% flows:	**6.71**	Total of Observed highest 10% flows:		**7.14**
Total of Simulated lowest 50% flows:	**4.95**	Total of Observed Lowest 50% flows:		**5.11**
Simulated Summer Flow Volume (months 7-9):	**5.35**	Observed Summer Flow Volume (7-9):		**4.96**
Simulated Fall Flow Volume (months 10-12):	**4.86**	Observed Fall Flow Volume (10-12):		**5.68**
Simulated Winter Flow Volume (months 1-3):	**4.62**	Observed Winter Flow Volume (1-3):		**4.78**
Simulated Spring Flow Volume (months 4-6):	**3.79**	Observed Spring Flow Volume (4-6):		**4.57**
Total Simulated Storm Volume:	**5.92**	Total Observed Storm Volume:		**6.54**
Simulated Summer Storm Volume (7-9)	**2.86**	Observed Summer Storm Volume (7-9):		**3.13**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*1995-1999*	*2000-2004*
Error in total volume:	-6.87	10	-1.43	7.35
Error in 50% lowest flows:	-3.26	10	-1.60	-3.91
Error in 10% highest flows:	-5.98	15	2.26	1.75
Seasonal volume error - Summer:	7.98	30	13.27	-2.52
Seasonal volume error - Fall:	-14.42	30	4.49	12.42
Seasonal volume error - Winter:	-3.40	30	-18.21	13.31
Seasonal volume error - Spring:	-17.22	30	1.90	6.11
Error in storm volumes:	-9.55	20	1.13	12.07
Error in summer storm volumes:	-8.76	50	3.16	15.42
Nash-Sutcliffe Coefficient of Efficiency, E:	0.818	Model accuracy increases	0.688	0.814
Baseline adjusted coefficient (Garrick), E':	0.482	as E or E' approaches 1.0	0.517	0.549

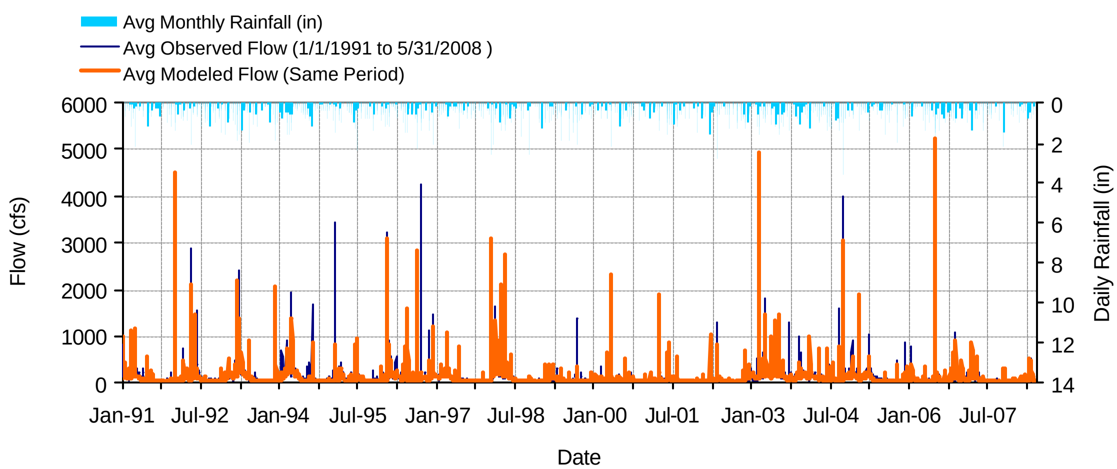

Figure E-22. Validation mean daily flow: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

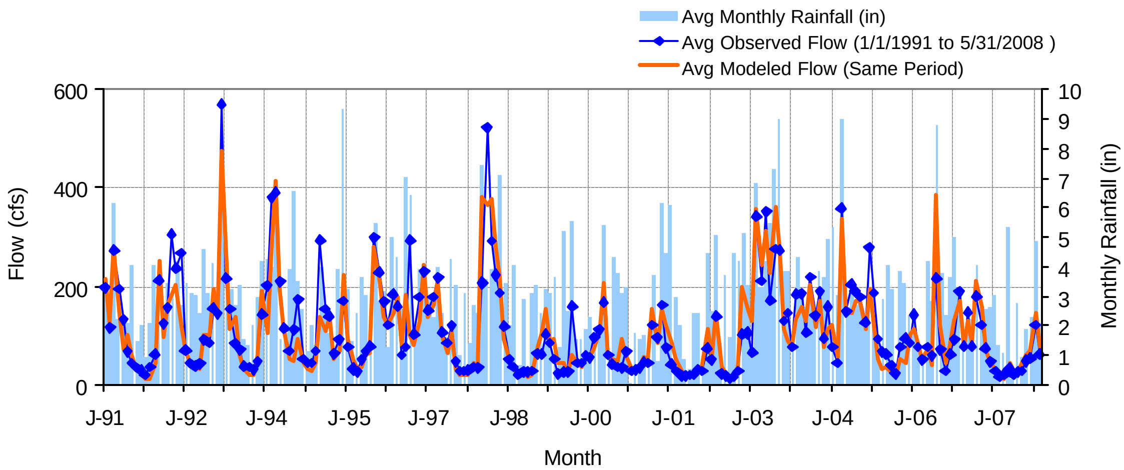

Figure E-23. Validation mean monthly flow: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

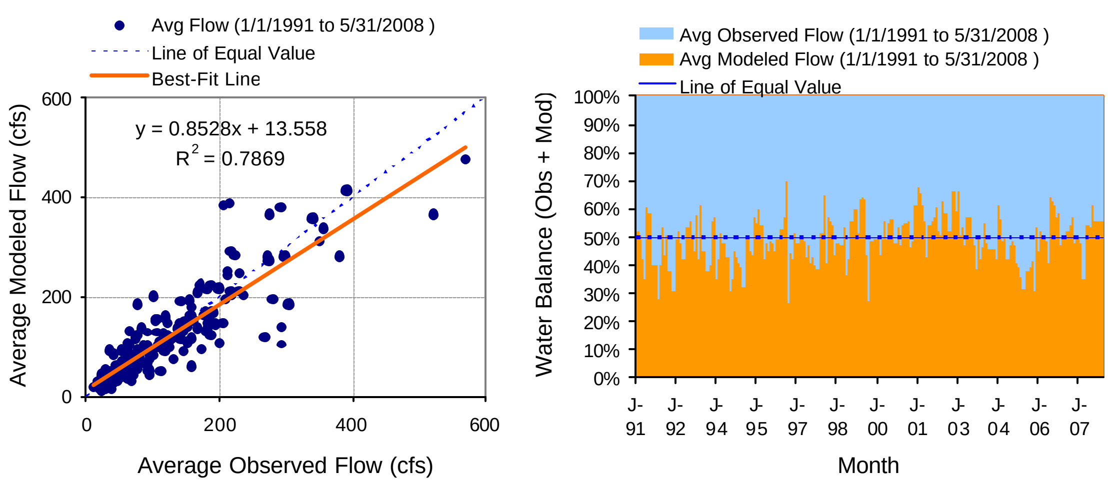

Figure E-24. Validation monthly flow regression and temporal variation: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

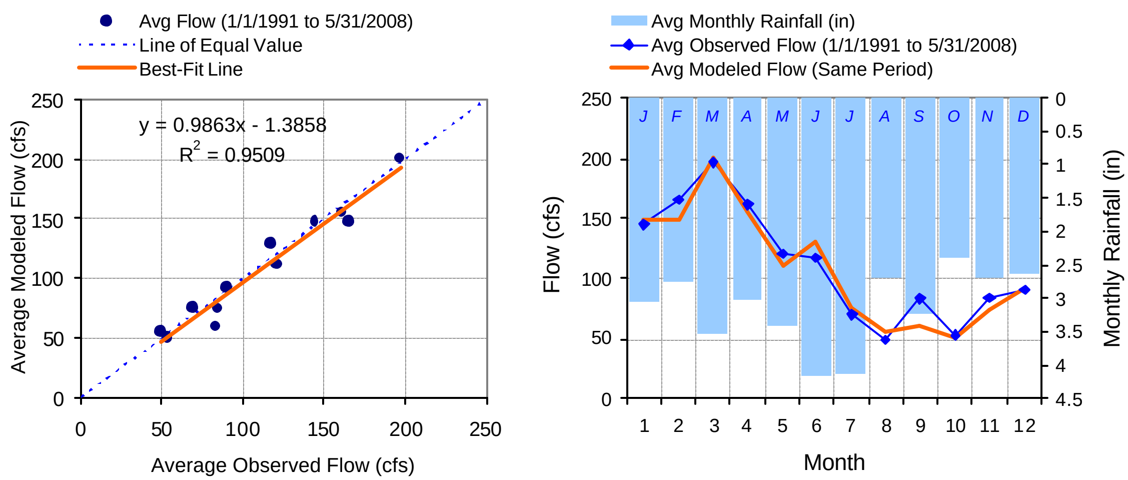

Figure E-25. Validation seasonal regression and temporal aggregate: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

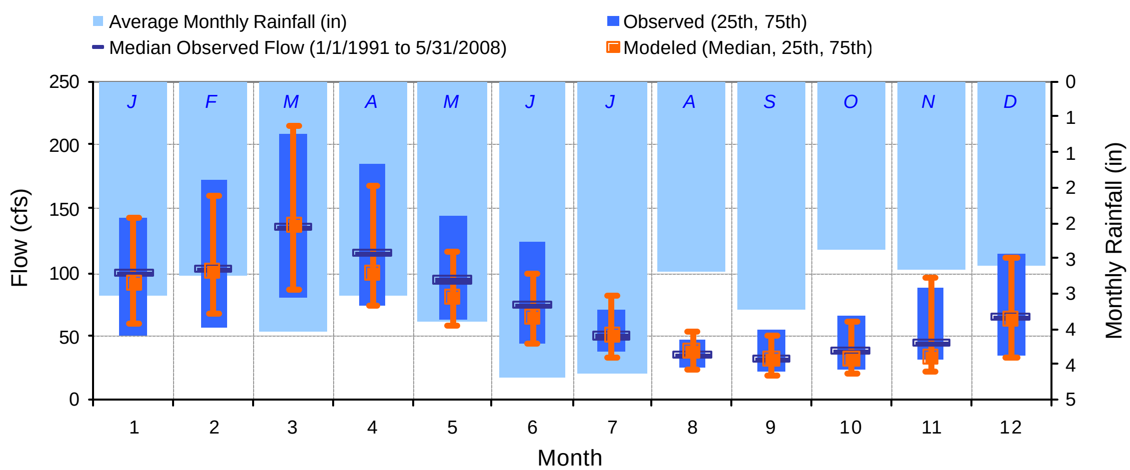

Figure E-26. Validation seasonal medians and ranges: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

Table E-7. Validation seasonal summary: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Jan	144.09	99.50	51.00	143.00	147.50	91.87	59.06	141.98
Feb	165.35	102.00	56.00	172.00	148.07	101.11	67.39	158.94
Mar	196.89	135.00	79.00	208.50	200.81	136.61	86.70	214.30
Apr	160.95	115.00	74.00	185.50	155.04	99.20	74.31	167.86
May	120.38	94.00	63.00	144.00	111.22	79.76	58.59	116.62
Jun	116.99	74.00	45.00	124.00	129.88	64.72	43.59	99.73
Jul	69.52	50.00	38.00	71.00	75.21	50.60	32.83	81.72
Aug	49.25	35.00	26.00	48.00	55.26	38.44	23.37	53.31
Sep	82.94	32.00	23.00	54.75	59.26	31.68	19.17	49.86
Oct	53.37	38.00	24.00	66.00	50.50	31.79	20.17	60.77
Nov	84.09	45.00	31.00	88.00	74.01	33.64	21.66	94.77
Dec	89.89	64.00	35.00	115.50	92.03	62.90	32.88	111.57

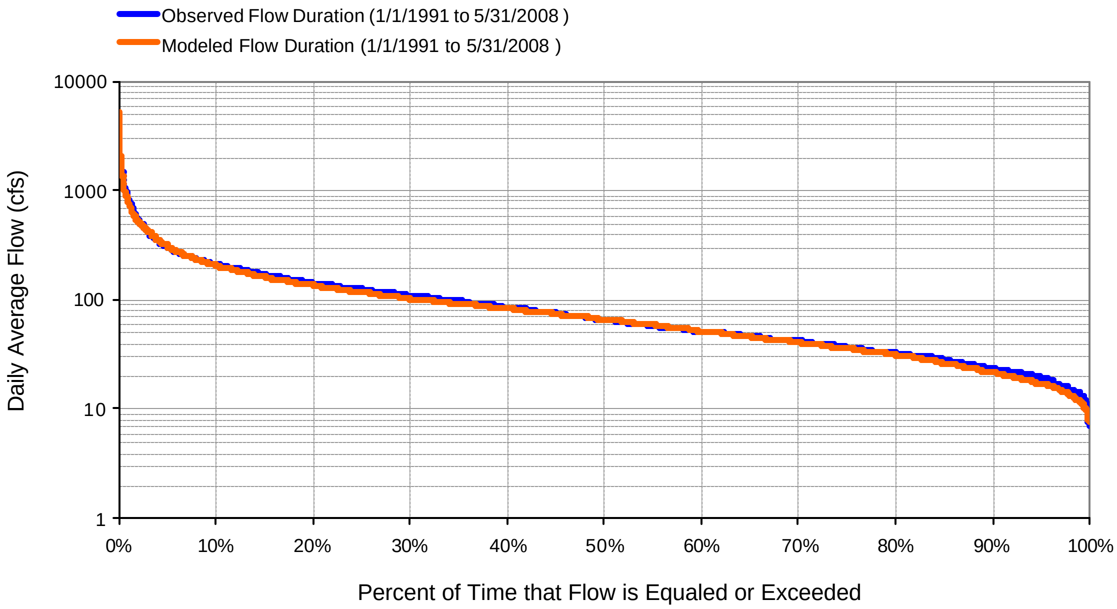

Figure E-27. Validation flow exceedence: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

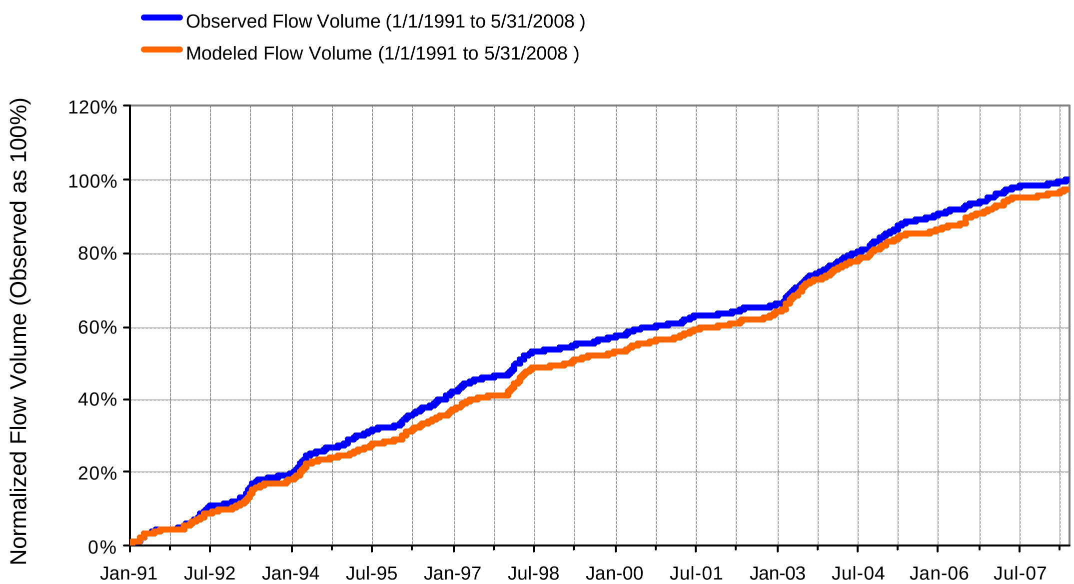

Figure E-28. Validation flow accumulation: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

Table E-8. Validation summary statistics: Model Outlet 3029 vs. USGS 02053800 S F Roanoke River Near Shawsville, VA

LSPC Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM SUBBASIN 3029 17.42-Year Analysis Period: 1/1/1991 - 5/31/2008 Flow volumes are (inches/year) for upstream drainage area		USGS 02053800 S F ROANOKE RIVER NEAR SHAWSVILLE, VA Hydrologic Unit Code: 3010101 Latitude: 37.1401323 Longitude: -80.2664328 Drainage Area (sq-mi): 109		
Total Simulated In-stream Flow:	**13.59**	Total Observed In-stream Flow:		**13.94**
Total of simulated highest 10% flows:	**5.70**	Total of Observed highest 10% flows:		**5.72**
Total of Simulated lowest 50% flows:	**2.29**	Total of Observed Lowest 50% flows:		**2.35**
Simulated Summer Flow Volume (months 7-9):	**1.94**	Observed Summer Flow Volume (7-9):		**2.05**
Simulated Fall Flow Volume (months 10-12):	**2.21**	Observed Fall Flow Volume (10-12):		**2.32**
Simulated Winter Flow Volume (months 1-3):	**5.28**	Observed Winter Flow Volume (1-3):		**5.38**
Simulated Spring Flow Volume (months 4-6):	**4.15**	Observed Spring Flow Volume (4-6):		**4.19**
Total Simulated Storm Volume:	**4.21**	Total Observed Storm Volume:		**4.24**
Simulated Summer Storm Volume (7-9)	**0.56**	Observed Summer Storm Volume (7-9):		**0.73**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*1995-1999*	*2000-2004*
Error in total volume:	-2.51	10	-1.43	7.35
Error in 50% lowest flows:	-2.56	10	-1.60	-3.91
Error in 10% highest flows:	-0.31	15	2.26	1.75
Seasonal volume error - Summer:	-5.64	30	13.27	-2.52
Seasonal volume error - Fall:	-4.66	30	4.49	12.42
Seasonal volume error - Winter:	-1.72	30	-18.21	13.31
Seasonal volume error - Spring:	-0.81	30	1.90	6.11
Error in storm volumes:	-0.75	20	1.13	12.07
Error in summer storm volumes:	-22.59	50	3.16	15.42
Nash-Sutcliffe Coefficient of Efficiency, E:	0.430	Model accuracy increases	0.688	0.814
Baseline adjusted coefficient (Garrick), E':	0.504	as E or E' approaches 1.0	0.517	0.549

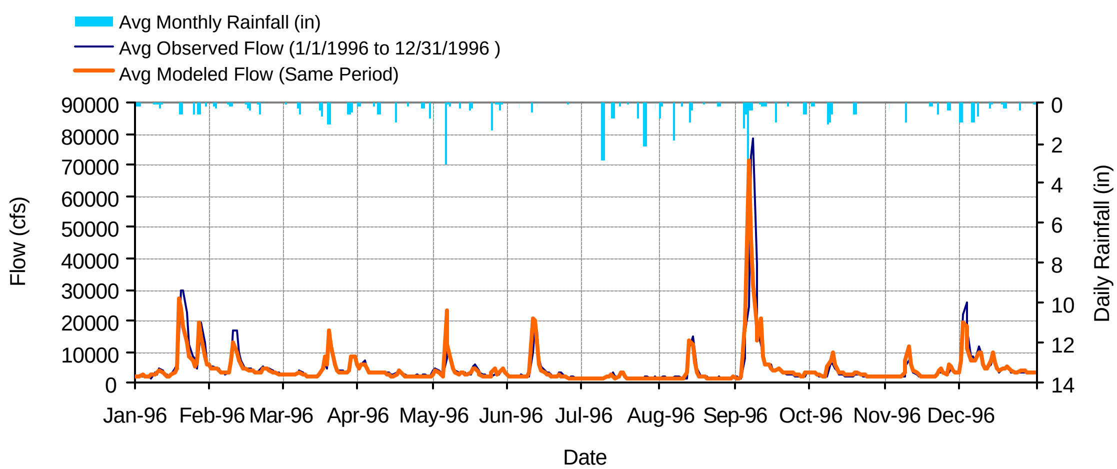

Figure E-29. Calibration mean daily flow: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

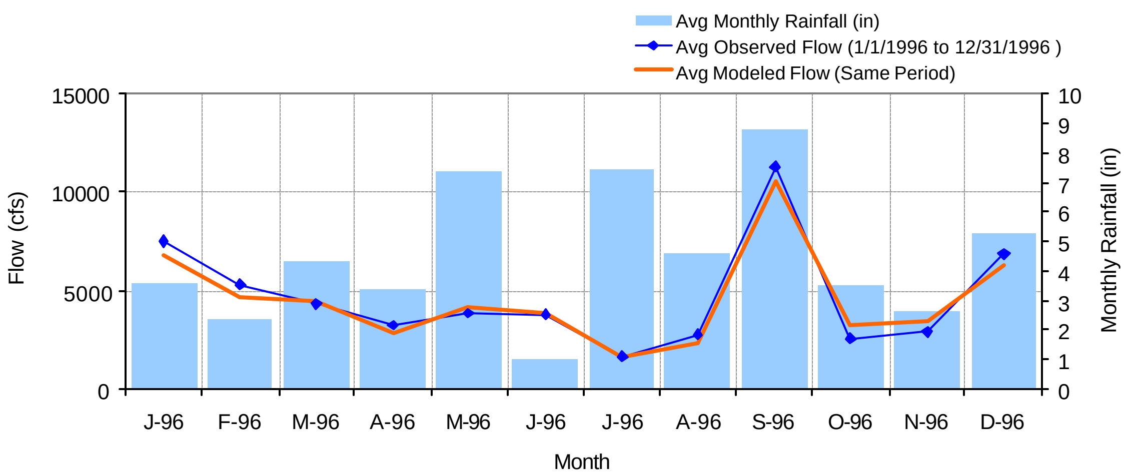

Figure E-30. Calibration mean monthly flow: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

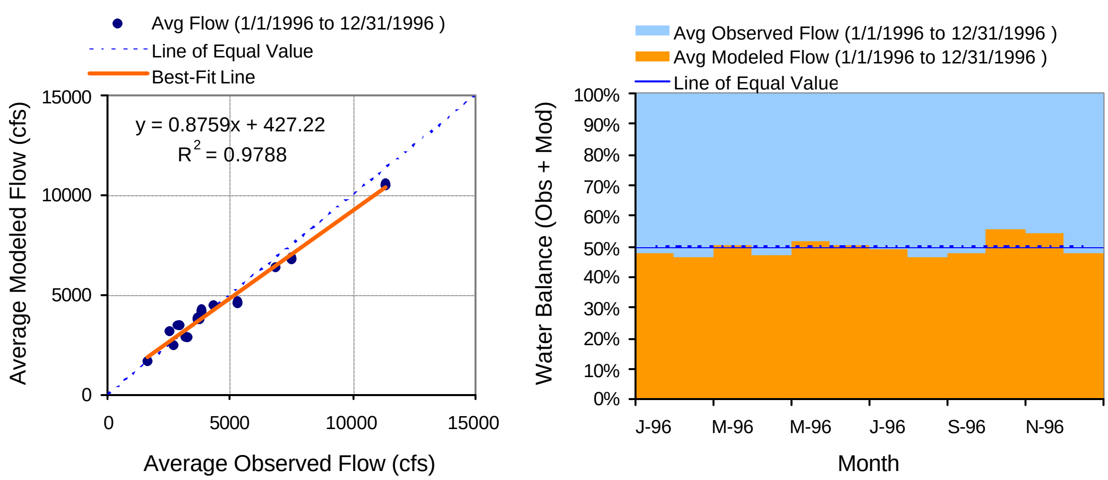

Figure E-31. Calibration monthly flow regression and temporal variation: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

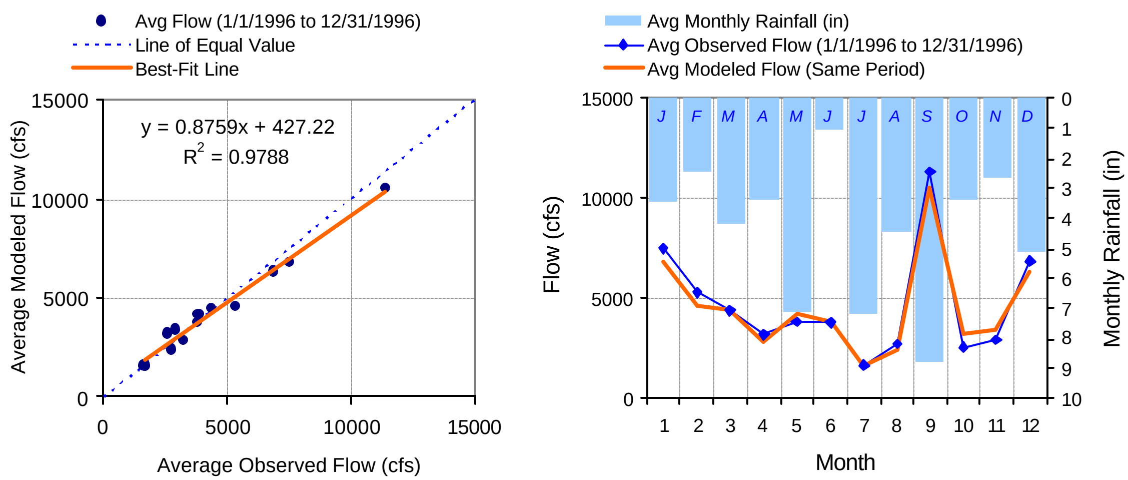

Figure E-32. Calibration seasonal regression and temporal aggregate: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

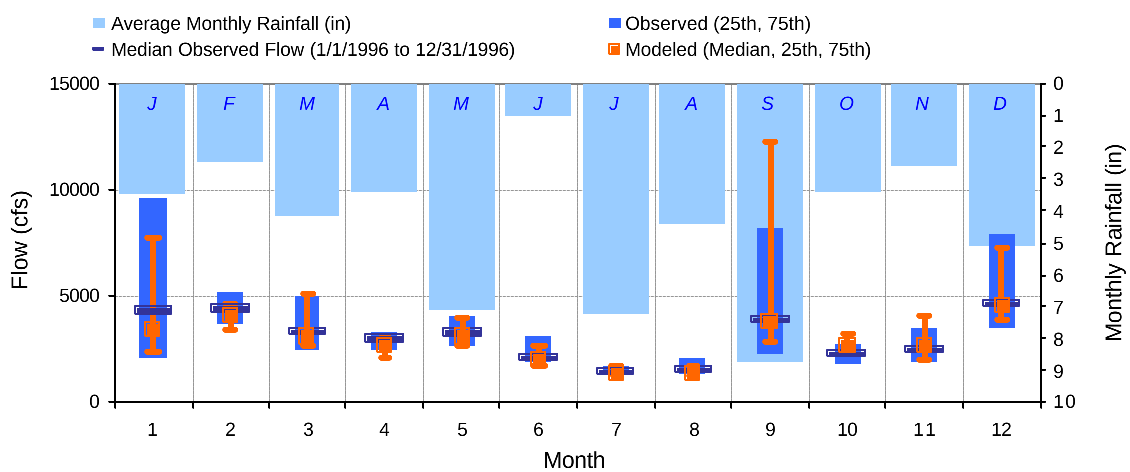

Figure E-33. Calibration seasonal medians and ranges: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

Table E-9. Calibration seasonal summary: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Jan	7511.29	4320.00	2025.00	9615.00	6806.82	3413.78	2368.68	7737.07
Feb	5315.86	4380.00	3680.00	5200.00	4618.06	4051.07	3401.95	4667.08
Mar	4360.00	3340.00	2500.00	4970.00	4453.88	3076.50	2682.13	5099.02
Apr	3230.33	2995.00	2435.00	3340.00	2873.64	2639.30	2078.70	3030.93
May	3834.52	3240.00	2630.00	4080.00	4183.42	3093.38	2634.64	3961.04
Jun	3755.33	2125.00	1862.50	3137.50	3792.11	2023.44	1714.45	2669.31
Jul	1660.32	1430.00	1325.00	1715.00	1620.99	1376.04	1309.44	1682.03
Aug	2757.10	1540.00	1370.00	2100.00	2419.64	1368.39	1215.25	1651.71
Sep	11348.00	3900.00	2242.50	8172.50	10552.90	3812.64	2895.65	12216.21
Oct	2593.23	2290.00	1825.00	2730.00	3208.20	2647.75	2248.63	3205.89
Nov	2919.33	2440.00	1890.00	3482.50	3432.63	2669.26	2014.73	3991.53
Dec	6886.77	4590.00	3465.00	7865.00	6364.00	4539.81	3879.30	7271.16

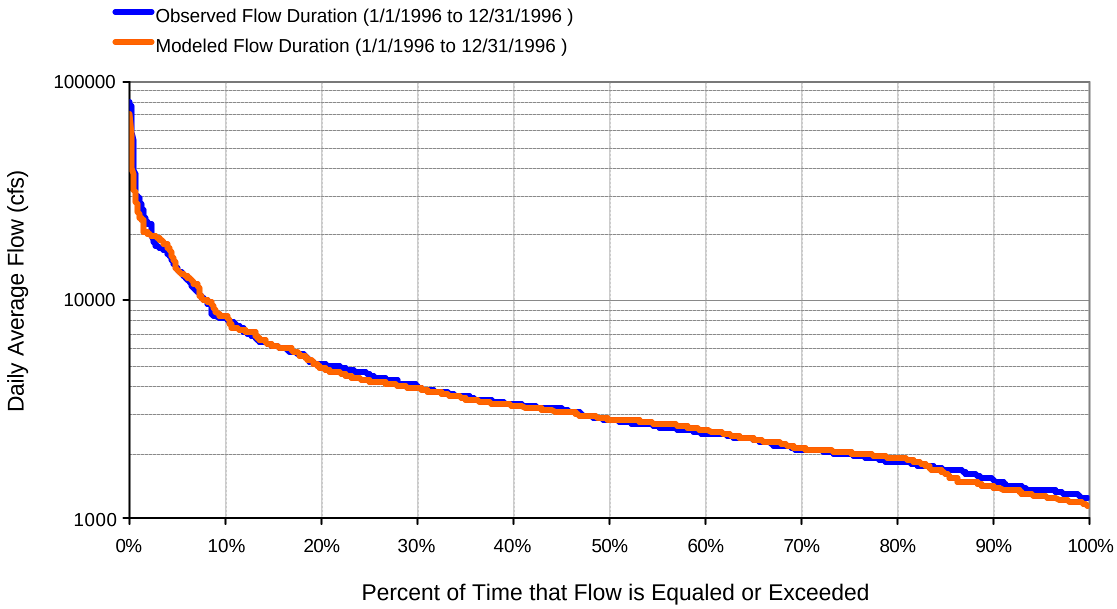

Figure E-34. Calibration flow exceedence: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

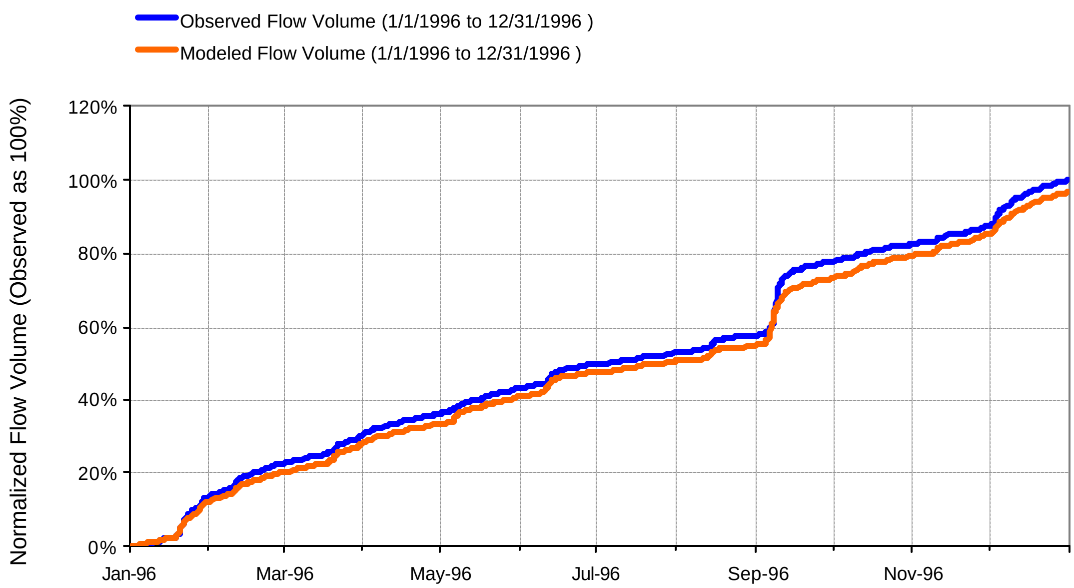

Figure E-35. Calibration flow accumulation: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

Table E-10. Calibration summary statistics: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

LSPC Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM SUBBASIN 1018 1-Year Analysis Period: 1/1/1996 - 12/31/1996 Flow volumes are (inches/year) for upstream drainage area		USGS 02066000 ROANOKE (STAUNTON) RIVER AT RANDOLPH, VA Hydrologic Unit Code: 3010102 Latitude: 36.91514189 Longitude: -78.7408384 Drainage Area (sq-mi): 2966		
Total Simulated In-stream Flow:	**20.70**	Total Observed In-stream Flow:		**21.39**
Total of simulated highest 10% flows:	**8.31**	Total of Observed highest 10% flows:		**8.87**
Total of Simulated lowest 50% flows:	**4.60**	Total of Observed Lowest 50% flows:		**4.59**
Simulated Summer Flow Volume (months 7-9):	**5.53**	Observed Summer Flow Volume (7-9):		**5.97**
Simulated Fall Flow Volume (months 10-12):	**5.00**	Observed Fall Flow Volume (10-12):		**4.77**
Simulated Winter Flow Volume (months 1-3):	**6.04**	Observed Winter Flow Volume (1-3):		**6.53**
Simulated Spring Flow Volume (months 4-6):	**4.13**	Observed Spring Flow Volume (4-6):		**4.11**
Total Simulated Storm Volume:	**9.60**	Total Observed Storm Volume:		**10.46**
Simulated Summer Storm Volume (7-9)	**3.31**	Observed Summer Storm Volume (7-9):		**3.82**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*1995-1999*	*2000-2004*
Error in total volume:	-3.23	10	-1.43	7.35
Error in 50% lowest flows:	0.33	10	-1.60	-3.91
Error in 10% highest flows:	-6.25	15	2.26	1.75
Seasonal volume error - Summer:	-7.44	30	13.27	-2.52
Seasonal volume error - Fall:	4.79	30	4.49	12.42
Seasonal volume error - Winter:	-7.50	30	-18.21	13.31
Seasonal volume error - Spring:	0.37	30	1.90	6.11
Error in storm volumes:	-8.24	20	1.13	12.07
Error in summer storm volumes:	-13.32	50	3.16	15.42
Nash-Sutcliffe Coefficient of Efficiency, E:	0.601	Model accuracy increases	0.688	0.814
Baseline adjusted coefficient (Garrick), E':	0.615	as E or E' approaches 1.0	0.517	0.549

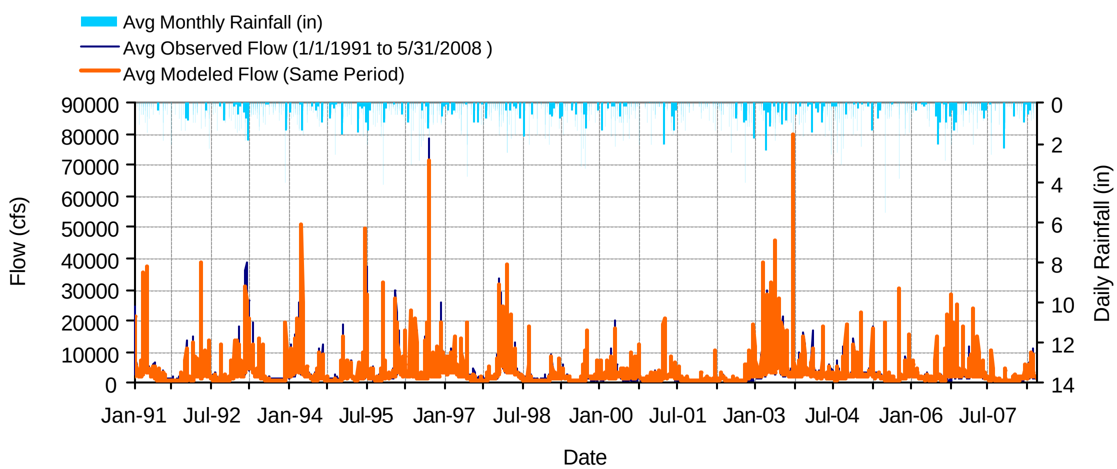

Figure E-36. Validation mean daily flow: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

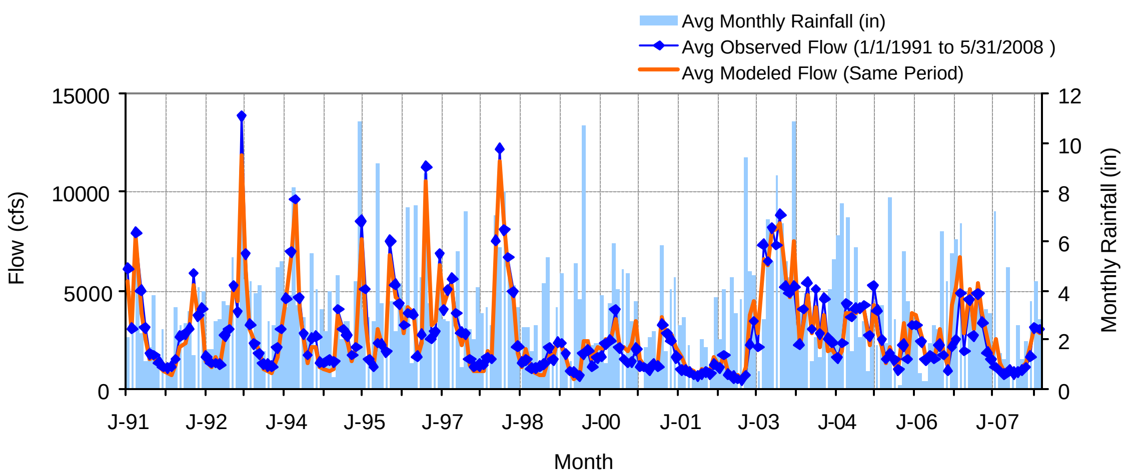

Figure E-37. Validation mean monthly flow: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

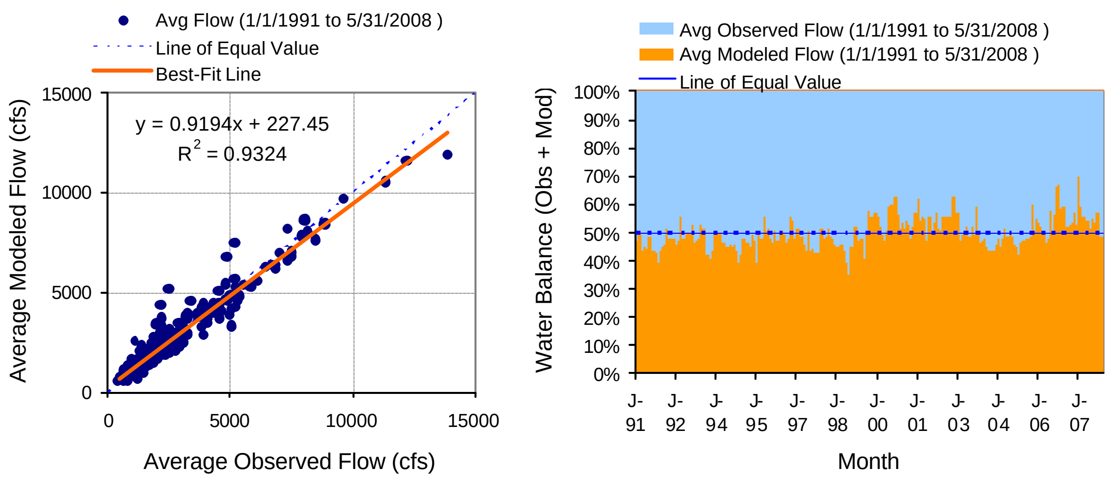

Figure E-38. Validation monthly flow regression and temporal variation: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

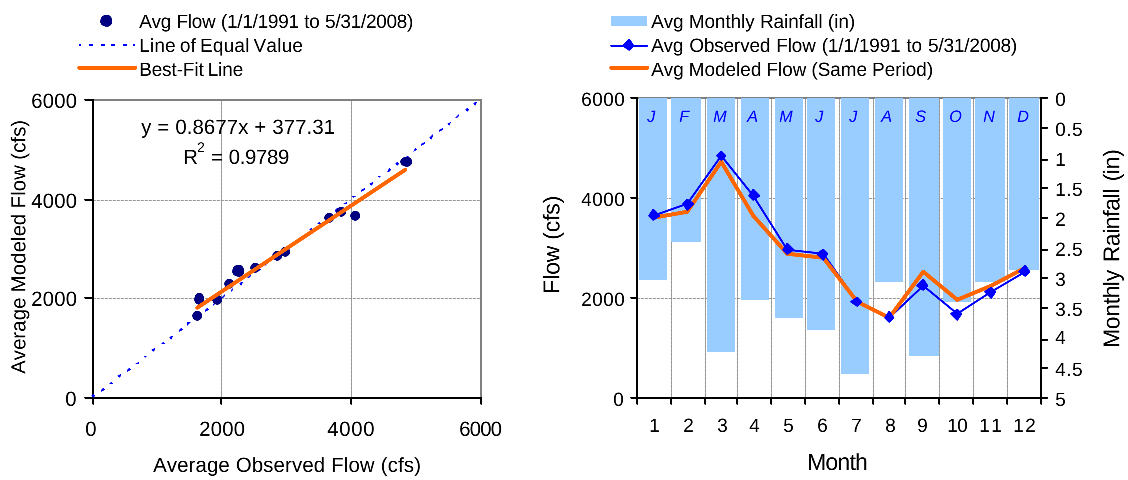

Figure E-39. Validation seasonal regression and temporal aggregate: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

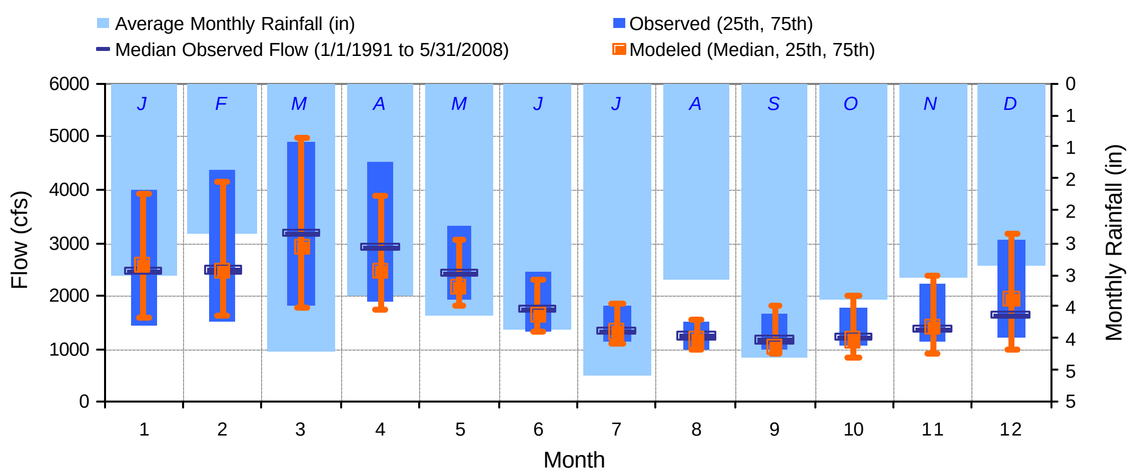

Figure E-40. Validation seasonal medians and ranges: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

Table E-11. Validation seasonal summary: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Jan	3663.28	2460.00	1422.50	3997.50	3609.07	2577.71	1575.72	3930.53
Feb	3866.63	2490.00	1500.00	4360.00	3726.05	2460.69	1634.47	4139.55
Mar	4850.44	3175.00	1812.50	4897.50	4742.02	2923.08	1759.46	4956.19
Apr	4065.82	2925.00	1870.00	4517.50	3648.59	2437.07	1732.52	3885.68
May	2986.95	2420.00	1940.00	3295.00	2911.51	2175.13	1805.68	3080.05
Jun	2866.51	1735.00	1320.00	2435.00	2834.51	1622.53	1297.41	2288.17
Jul	1926.30	1340.00	1140.00	1810.00	1943.53	1309.90	1088.42	1847.53
Aug	1627.64	1220.00	998.50	1510.00	1630.14	1154.08	977.55	1539.24
Sep	2269.43	1170.00	982.50	1655.00	2536.19	1034.03	897.11	1801.26
Oct	1669.62	1210.00	1060.00	1745.00	1968.24	1152.95	847.47	2009.16
Nov	2126.20	1365.00	1140.00	2227.50	2266.36	1418.57	901.19	2368.25
Dec	2533.98	1630.00	1190.00	3060.00	2607.77	1953.03	993.08	3169.05

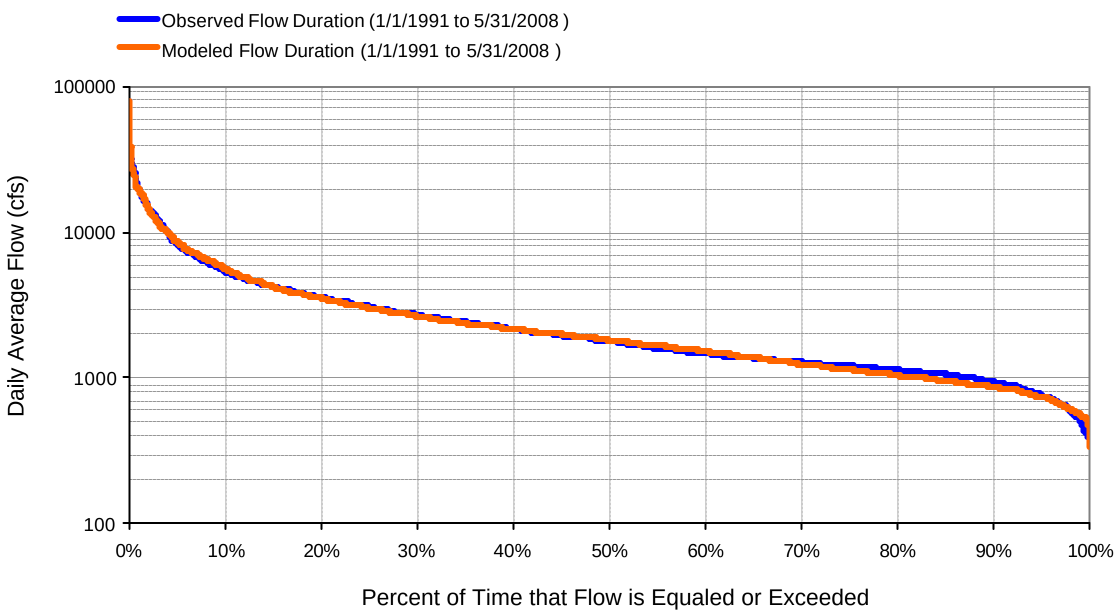

Figure E-41. Validation flow exceedence: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

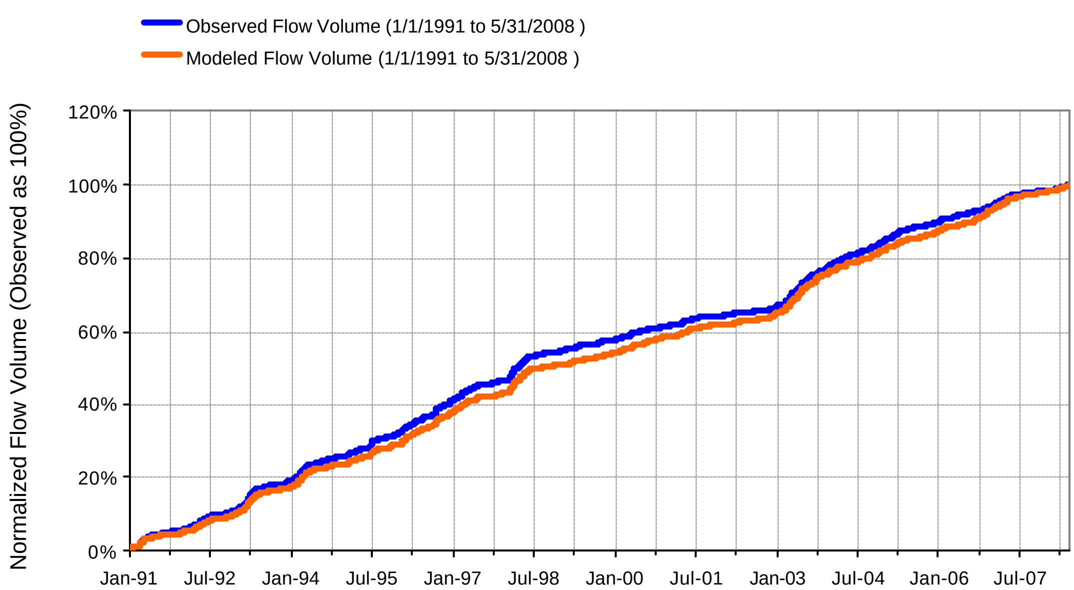

Figure E-42. Validation flow accumulation: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

Table E-12. Validation summary statistics: Model Outlet 1018 vs. USGS 02066000 Roanoke (Staunton) River At Randolph, VA

LSPC Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM SUBBASIN 1018 17.42-Year Analysis Period: 1/1/1991 - 5/31/2008 Flow volumes are (inches/year) for upstream drainage area		USGS 02066000 ROANOKE (STAUNTON) RIVER AT RANDOLPH, VA Hydrologic Unit Code: 3010102 Latitude: 36.91514189 Longitude: -78.7408384 Drainage Area (sq-mi): 2966		
Total Simulated In-stream Flow:	**13.21**	Total Observed In-stream Flow:		**13.23**
Total of simulated highest 10% flows:	**5.18**	Total of Observed highest 10% flows:		**5.13**
Total of Simulated lowest 50% flows:	**2.67**	Total of Observed Lowest 50% flows:		**2.72**
Simulated Summer Flow Volume (months 7-9):	**2.29**	Observed Summer Flow Volume (7-9):		**2.18**
Simulated Fall Flow Volume (months 10-12):	**2.57**	Observed Fall Flow Volume (10-12):		**2.38**
Simulated Winter Flow Volume (months 1-3):	**4.72**	Observed Winter Flow Volume (1-3):		**4.84**
Simulated Spring Flow Volume (months 4-6):	**3.63**	Observed Spring Flow Volume (4-6):		**3.83**
Total Simulated Storm Volume:	**5.09**	Total Observed Storm Volume:		**4.97**
Simulated Summer Storm Volume (7-9)	**0.91**	Observed Summer Storm Volume (7-9):		**0.80**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*1995-1999*	*2000-2004*
Error in total volume:	-0.17	10	-1.43	7.35
Error in 50% lowest flows:	-1.77	10	-1.60	-3.91
Error in 10% highest flows:	0.93	15	2.26	1.75
Seasonal volume error - Summer:	4.83	30	13.27	-2.52
Seasonal volume error - Fall:	8.11	30	4.49	12.42
Seasonal volume error - Winter:	-2.42	30	-18.21	13.31
Seasonal volume error - Spring:	-5.33	30	1.90	6.11
Error in storm volumes:	2.59	20	1.13	12.07
Error in summer storm volumes:	13.24	50	3.16	15.42
Nash-Sutcliffe Coefficient of Efficiency, E:	0.640	Model accuracy increases	0.688	0.814
Baseline adjusted coefficient (Garrick), E':	0.635	as E or E' approaches 1.0	0.517	0.549

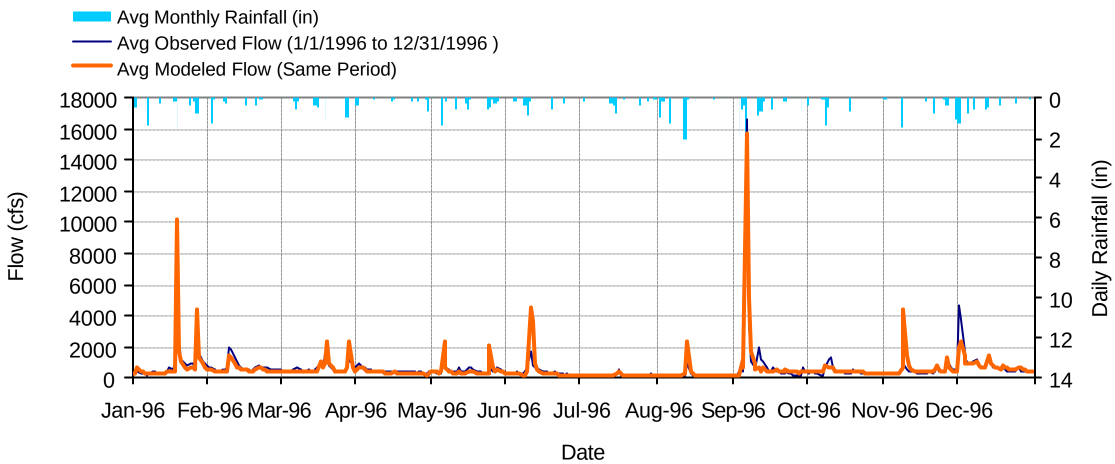

Figure E-43. Calibration mean daily flow: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

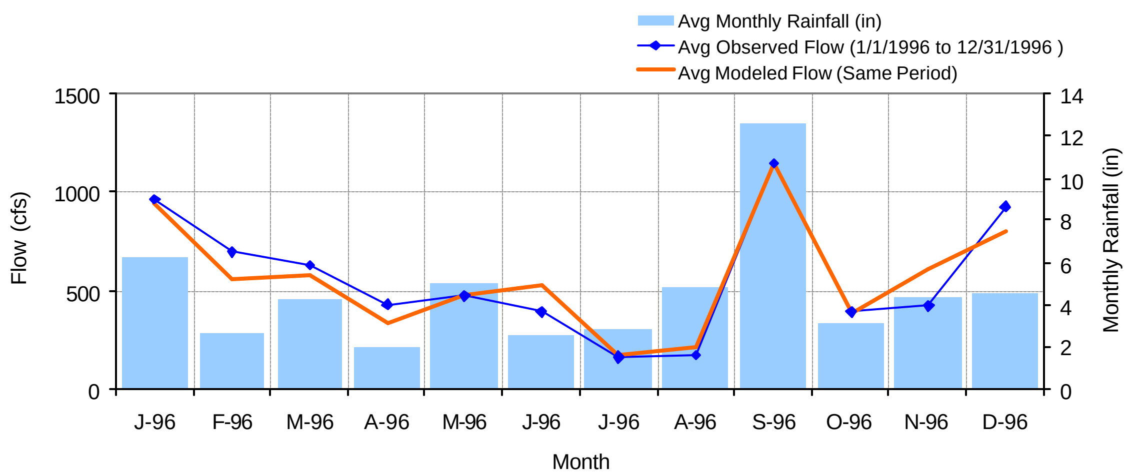

Figure E-44. Calibration mean monthly flow: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

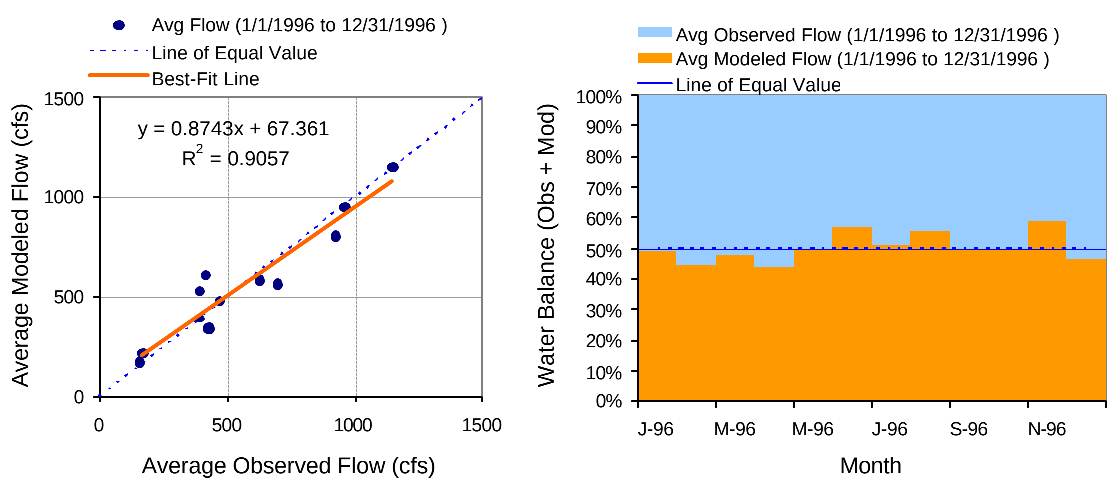

Figure E-45. Calibration mean monthly flow regression and temporal variation: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

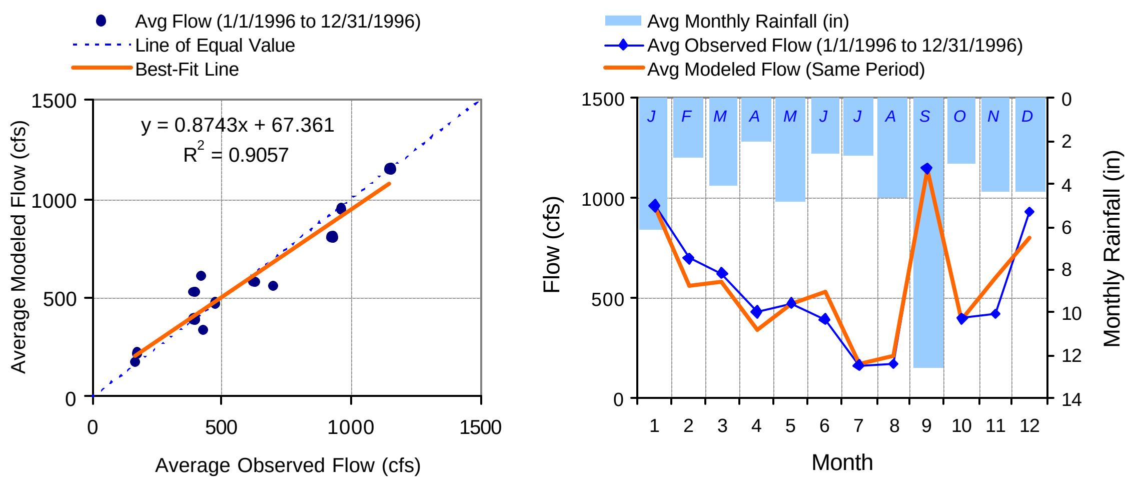

Figure E-46. Calibration seasonal regression and temporal aggregate: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

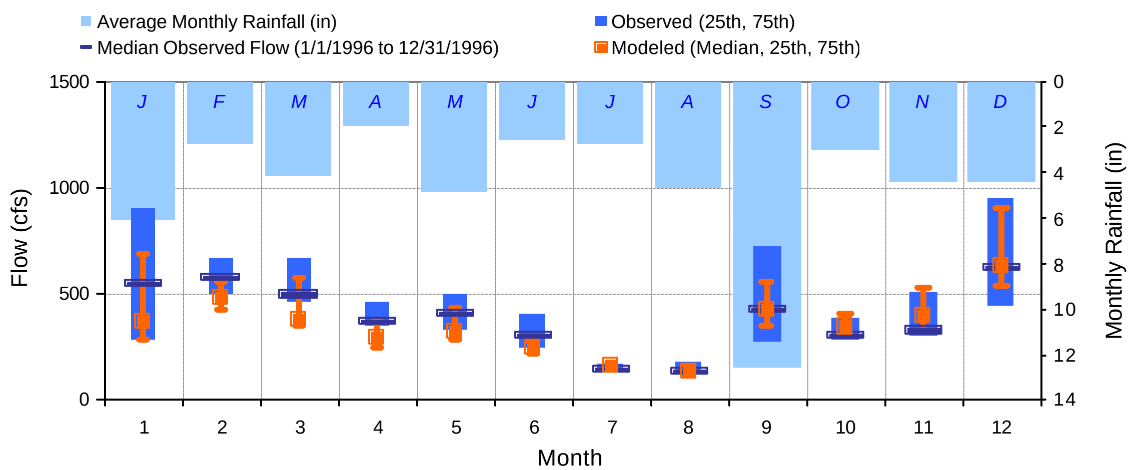

Figure E-47. Calibration seasonal medians and ranges: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

Table E-13. Calibration seasonal summary: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Jan	962.13	549.00	278.00	909.00	945.33	367.36	279.14	685.69
Feb	700.17	575.00	500.00	675.00	561.75	478.34	428.70	549.15
Mar	628.61	495.00	455.00	668.00	583.18	380.54	348.25	571.28
Apr	431.07	371.00	341.75	457.75	337.48	296.76	251.68	369.97
May	474.10	405.00	331.50	503.50	474.75	321.55	281.19	430.24
Jun	392.83	301.50	247.00	404.00	529.67	246.09	220.62	276.87
Jul	164.55	143.00	127.50	164.50	173.58	161.80	147.73	174.25
Aug	174.48	131.00	122.00	181.50	220.16	129.54	121.52	153.62
Sep	1149.87	422.00	275.75	722.25	1146.05	425.38	349.82	553.89
Oct	394.48	302.00	284.00	379.00	388.92	347.66	314.22	405.42
Nov	420.97	325.50	304.75	505.75	609.37	396.29	319.14	528.49
Dec	928.16	625.00	441.50	950.50	802.33	637.51	538.09	905.10

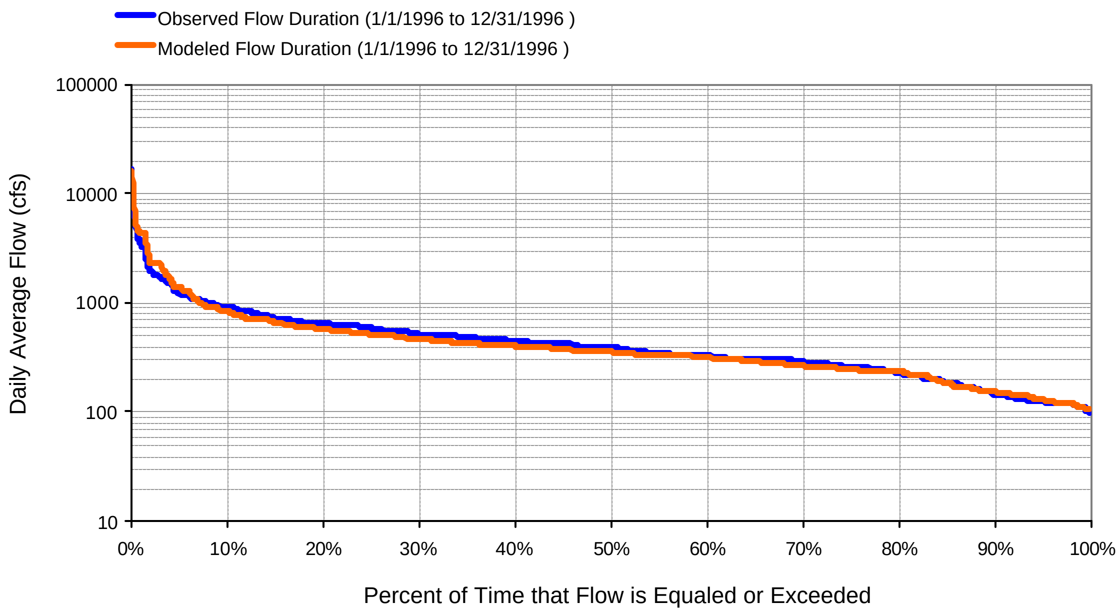

Figure E-48. Calibration flow exceedence: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

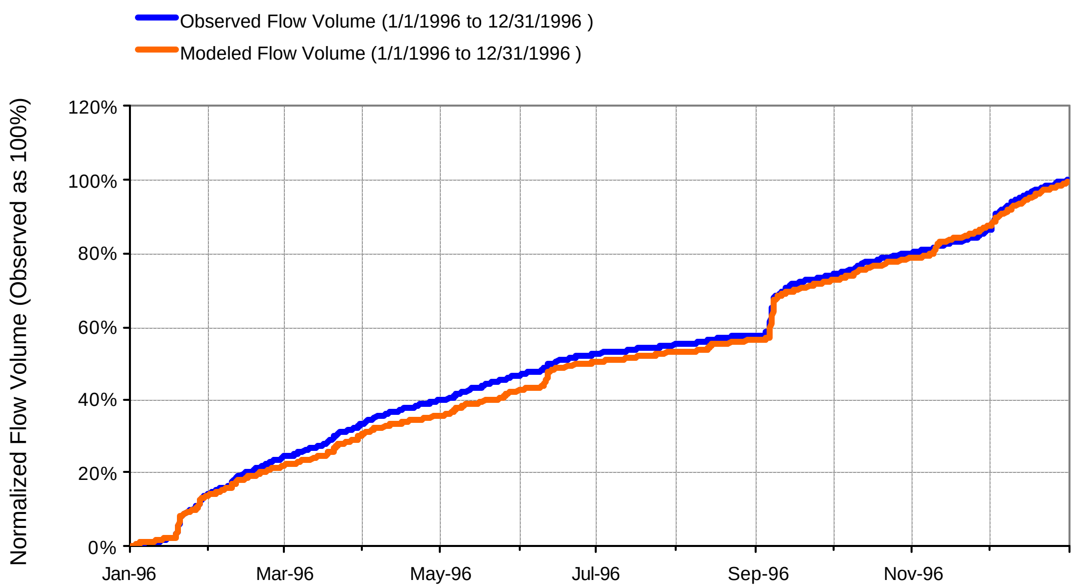

Figure E-49. Calibration flow accumulation: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

Table E-14. Calibration summary statistics: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

LSPC Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM SUBBASIN 1070 1-Year Analysis Period: 1/1/1996 - 12/31/1996 Flow volumes are (inches/year) for upstream drainage area		USGS 02061500 BIG OTTER RIVER NEAR EVINGTON, VA Hydrologic Unit Code: 3010101 Latitude: 37.20847738 Longitude: -79.3036357 Drainage Area (sq-mi): 315		
Total Simulated In-stream Flow:	**24.30**	Total Observed In-stream Flow:		**24.47**
Total of simulated highest 10% flows:	**10.65**	Total of Observed highest 10% flows:		**9.60**
Total of Simulated lowest 50% flows:	**5.18**	Total of Observed Lowest 50% flows:		**5.37**
Simulated Summer Flow Volume (months 7-9):	**5.49**	Observed Summer Flow Volume (7-9):		**5.30**
Simulated Fall Flow Volume (months 10-12):	**6.50**	Observed Fall Flow Volume (10-12):		**6.32**
Simulated Winter Flow Volume (months 1-3):	**7.50**	Observed Winter Flow Volume (1-3):		**8.20**
Simulated Spring Flow Volume (months 4-6):	**4.80**	Observed Spring Flow Volume (4-6):		**4.64**
Total Simulated Storm Volume:	**10.95**	Total Observed Storm Volume:		**10.22**
Simulated Summer Storm Volume (7-9)	**3.32**	Observed Summer Storm Volume (7-9):		**3.35**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*1995-1999*	*2000-2004*
Error in total volume:	-0.71	10	-1.43	7.35
Error in 50% lowest flows:	-3.43	10	-1.60	-3.91
Error in 10% highest flows:	10.92	15	2.26	1.75
Seasonal volume error - Summer:	3.51	30	13.27	-2.52
Seasonal volume error - Fall:	2.94	30	4.49	12.42
Seasonal volume error - Winter:	-8.54	30	-18.21	13.31
Seasonal volume error - Spring:	3.34	30	1.90	6.11
Error in storm volumes:	7.07	20	1.13	12.07
Error in summer storm volumes:	-0.91	50	3.16	15.42
Nash-Sutcliffe Coefficient of Efficiency, E:	0.848	Model accuracy increases	0.688	0.814
Baseline adjusted coefficient (Garrick), E':	0.553	as E or E' approaches 1.0	0.517	0.549

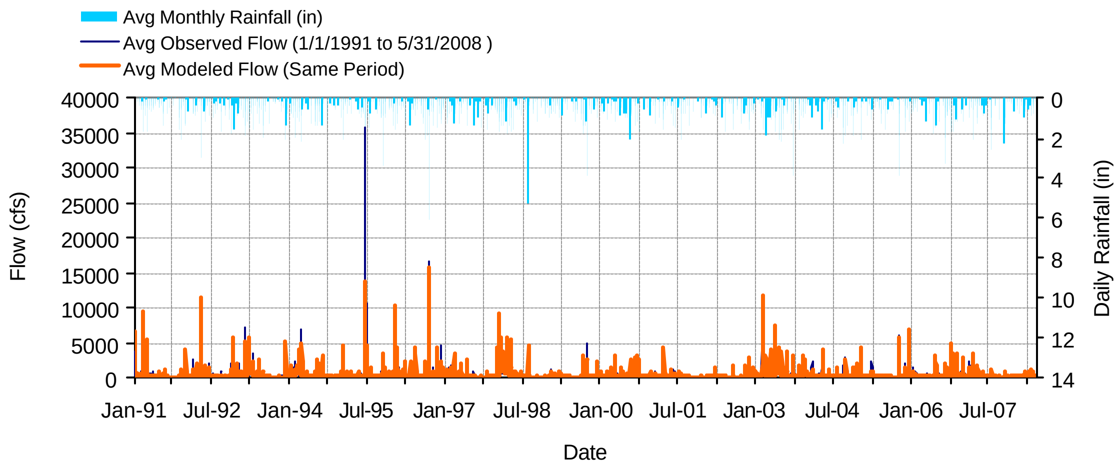

Figure E-50. Validation mean daily flow: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

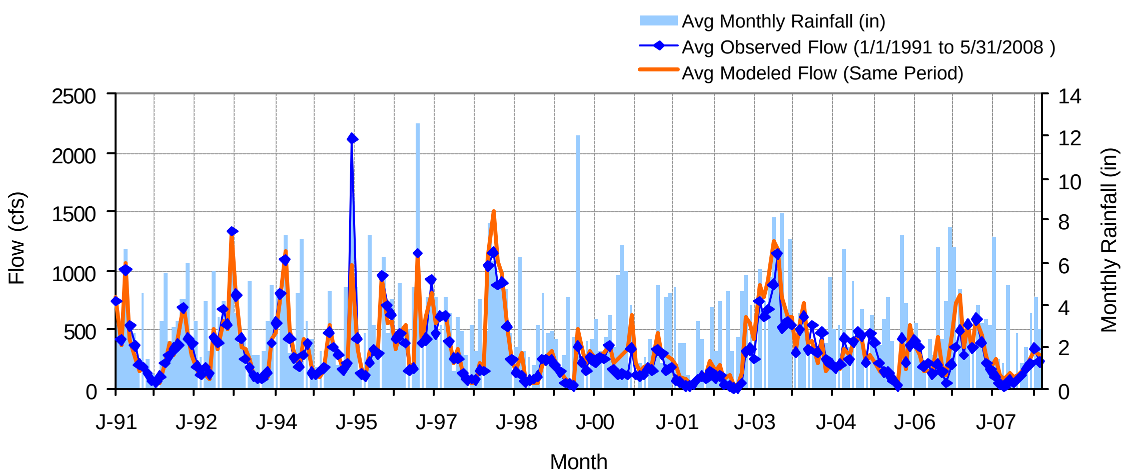

Figure E-51. Validation mean monthly flow: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

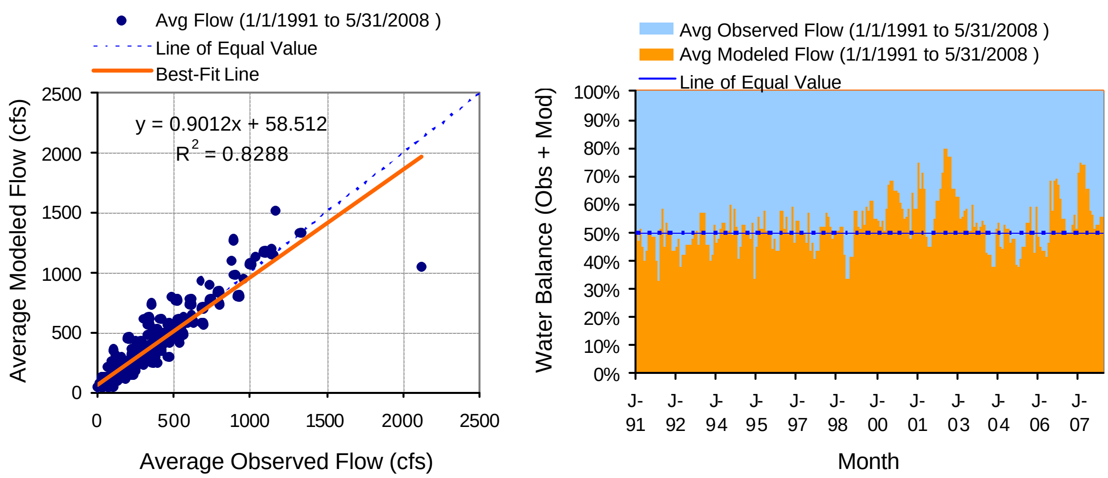

Figure E-52. Validation monthly flow regression and temporal variation: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

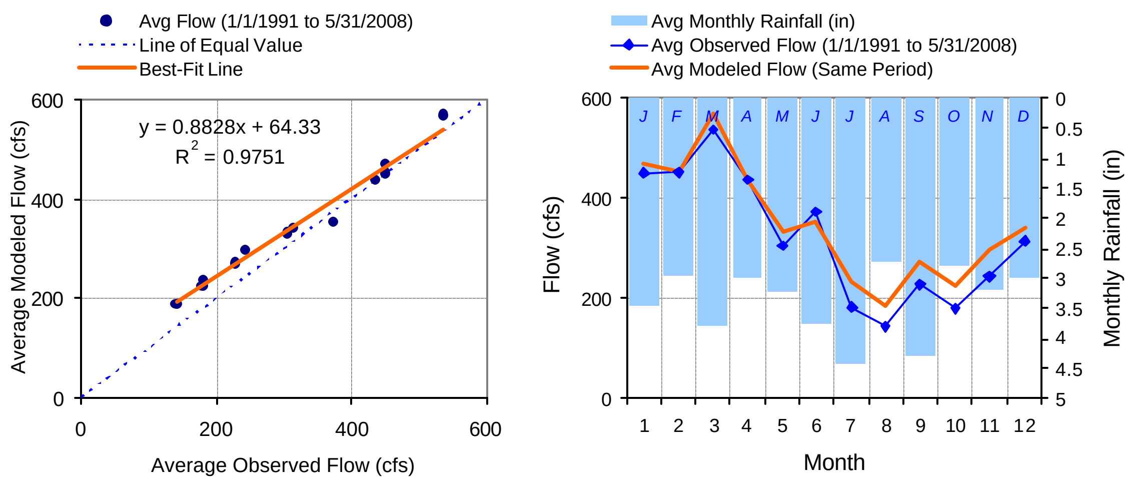

Figure E-52. Validation seasonal regression and temporal aggregate: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

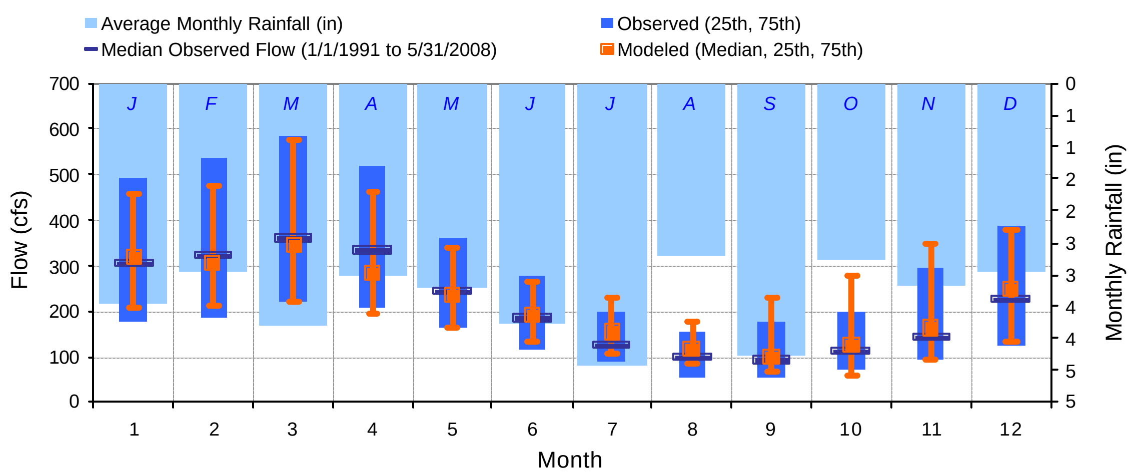

Figure E-53. Validation seasonal medians and ranges: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

Table E-15. Validation seasonal summary: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Jan	450.18	305.00	176.50	494.00	470.28	318.13	208.76	455.08
Feb	451.06	320.00	183.00	535.00	451.33	303.11	211.18	476.75
Mar	535.23	358.00	220.00	581.00	568.33	344.30	218.99	576.50
Apr	436.67	334.00	203.75	520.25	438.04	282.91	193.13	461.59
May	306.10	243.00	159.25	359.75	331.14	236.24	162.84	336.34
Jun	373.74	184.00	117.25	278.75	352.02	190.15	134.83	264.19
Jul	181.32	127.00	85.50	199.50	235.12	151.80	107.78	227.17
Aug	142.40	97.00	53.00	152.00	186.59	114.66	84.31	174.72
Sep	228.67	92.50	51.00	174.00	271.43	97.94	66.10	227.45
Oct	179.49	112.00	70.00	200.00	223.51	125.75	55.92	278.37
Nov	244.29	140.50	94.00	294.50	298.16	161.81	91.90	350.09
Dec	315.04	225.00	124.00	388.50	339.79	248.53	132.19	377.19

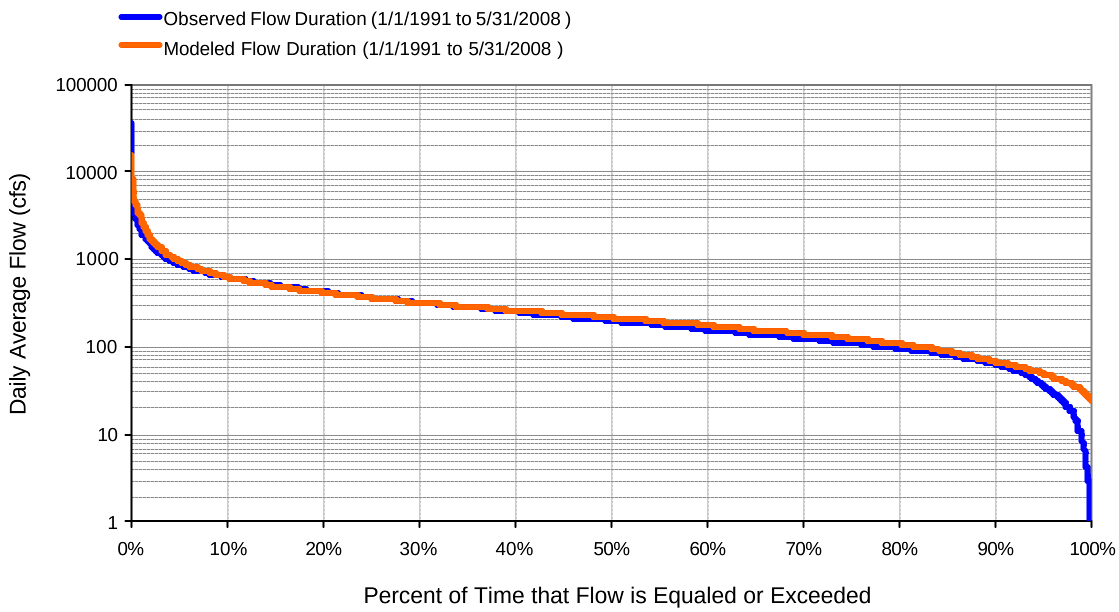

Figure E-54. Validation flow exceedence: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

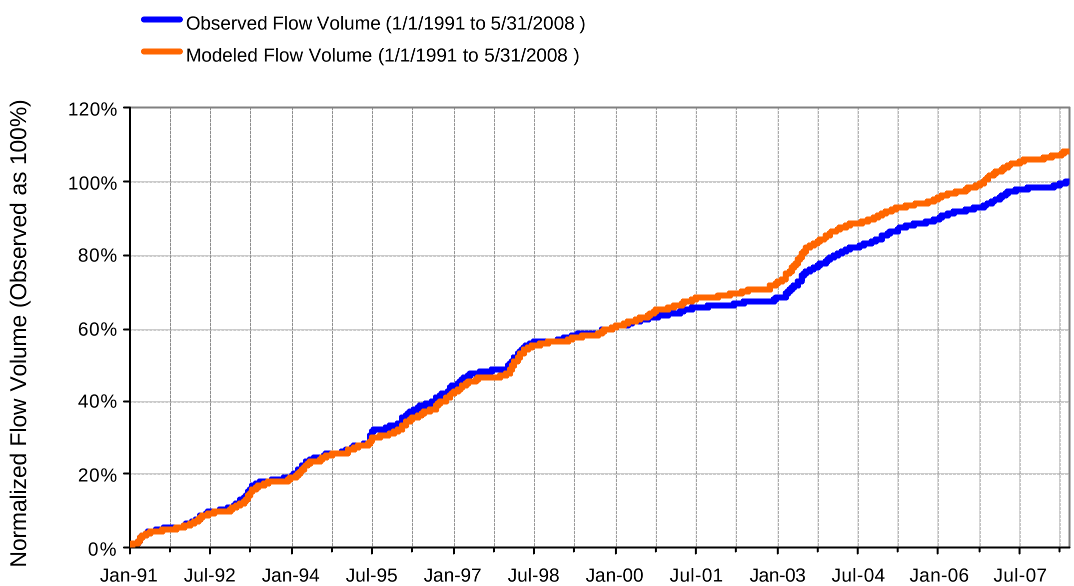

Figure E-55. Validation flow accumulation: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

Table E-16. Validation summary statistics: Model Outlet 1070 vs. USGS 02061500 Big Otter River Near Evington, VA

LSPC Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM SUBBASIN 1070 17.42-Year Analysis Period: 1/1/1991 - 5/31/2008 Flow volumes are (inches/year) for upstream drainage area		USGS 02061500 BIG OTTER RIVER NEAR EVINGTON, VA Hydrologic Unit Code: 3010101 Latitude: 37.20847738 Longitude: -79.3036357 Drainage Area (sq-mi): 315		
Total Simulated In-stream Flow:	**15.05**	Total Observed In-stream Flow:		**13.89**
Total of simulated highest 10% flows:	**6.44**	Total of Observed highest 10% flows:		**5.63**
Total of Simulated lowest 50% flows:	**2.63**	Total of Observed Lowest 50% flows:		**2.32**
Simulated Summer Flow Volume (months 7-9):	**2.45**	Observed Summer Flow Volume (7-9):		**1.95**
Simulated Fall Flow Volume (months 10-12):	**3.04**	Observed Fall Flow Volume (10-12):		**2.61**
Simulated Winter Flow Volume (months 1-3):	**5.49**	Observed Winter Flow Volume (1-3):		**5.28**
Simulated Spring Flow Volume (months 4-6):	**4.07**	Observed Spring Flow Volume (4-6):		**4.05**
Total Simulated Storm Volume:	**5.80**	Total Observed Storm Volume:		**5.05**
Simulated Summer Storm Volume (7-9)	**1.02**	Observed Summer Storm Volume (7-9):		**0.81**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*1995-1999*	*2000-2004*
Error in total volume:	8.33	10	-1.43	7.35
Error in 50% lowest flows:	13.47	10	-1.60	-3.91
Error in 10% highest flows:	14.47	15	2.26	1.75
Seasonal volume error - Summer:	25.57	30	13.27	-2.52
Seasonal volume error - Fall:	16.54	30	4.49	12.42
Seasonal volume error - Winter:	3.83	30	-18.21	13.31
Seasonal volume error - Spring:	0.61	30	1.90	6.11
Error in storm volumes:	14.91	20	1.13	12.07
Error in summer storm volumes:	25.99	50	3.16	15.42
Nash-Sutcliffe Coefficient of Efficiency, E:	0.591	Model accuracy increases	0.688	0.814
Baseline adjusted coefficient (Garrick), E':	0.529	as E or E' approaches 1.0	0.517	0.549

Appendix F: Roanoke River PCB TMDL Model Water Quality Calibration Results

LIST OF FIGURES

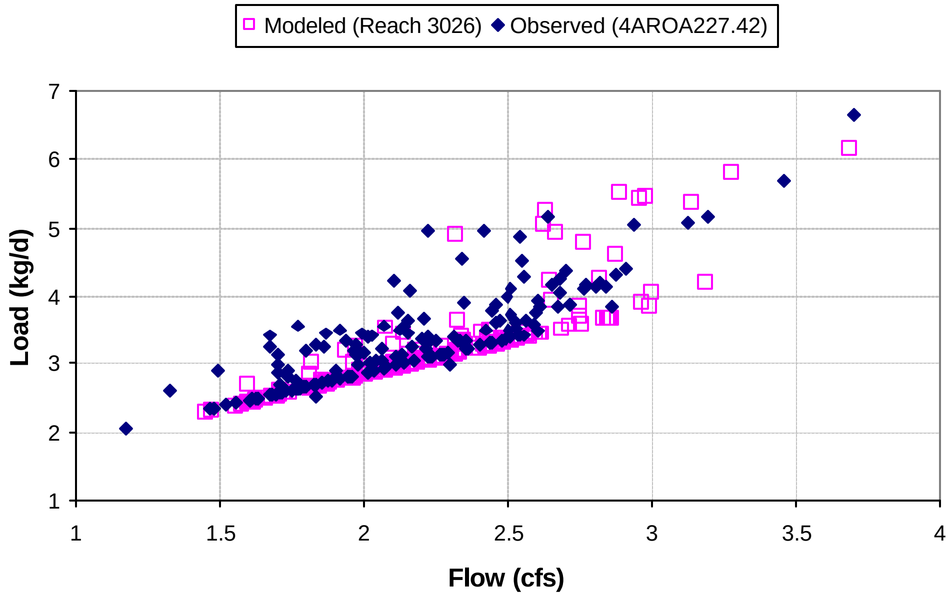

Figure F-1. Modeled vs. Observed Antilog Suspended Solids Loads (kg/d) at 4AROA227.42

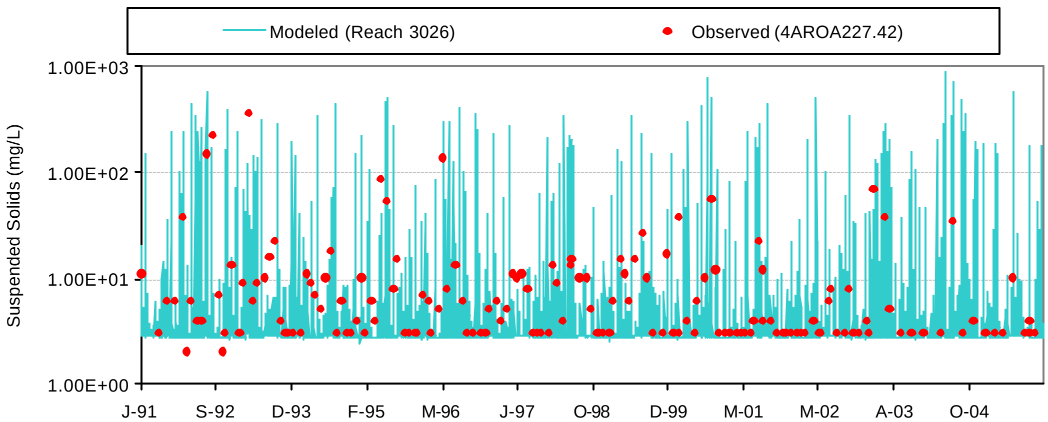

Figure F-2. Modeled vs. Observed Suspended Solids (mg/L) at 4AROA227.42

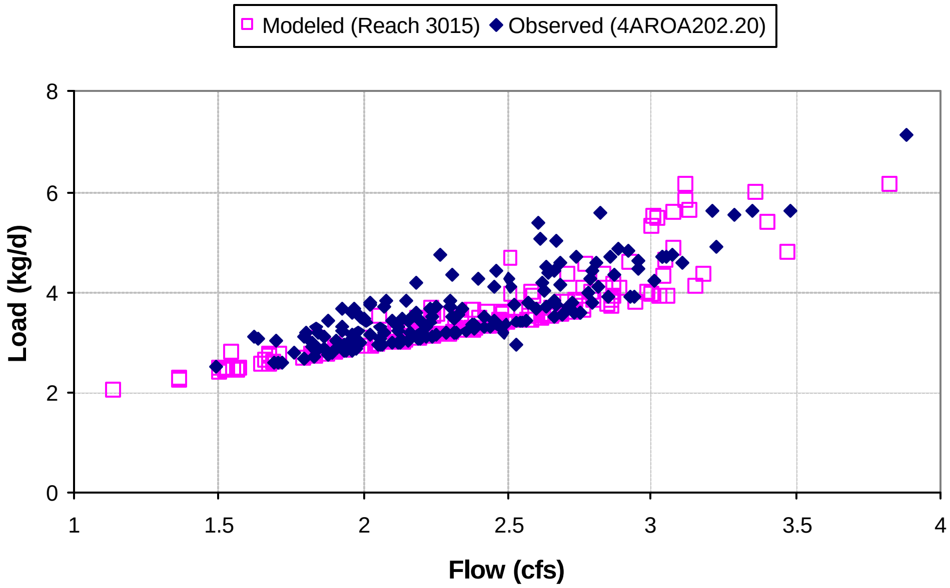

Figure F-3. Modeled vs. Observed Antilog Suspended Solids Loads (kg/d) at 4AROA202.20

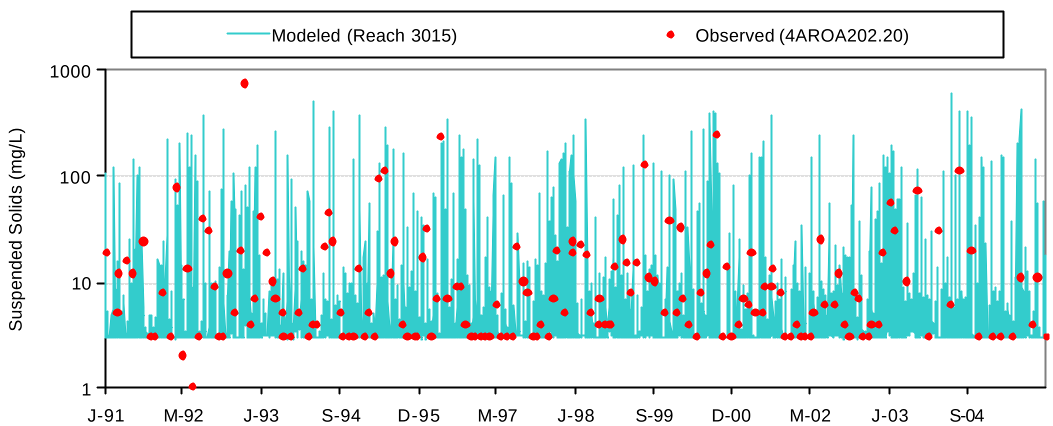

Figure F-4. Modeled vs. Observed Suspended Solids (mg/L) at 4AROA202.20

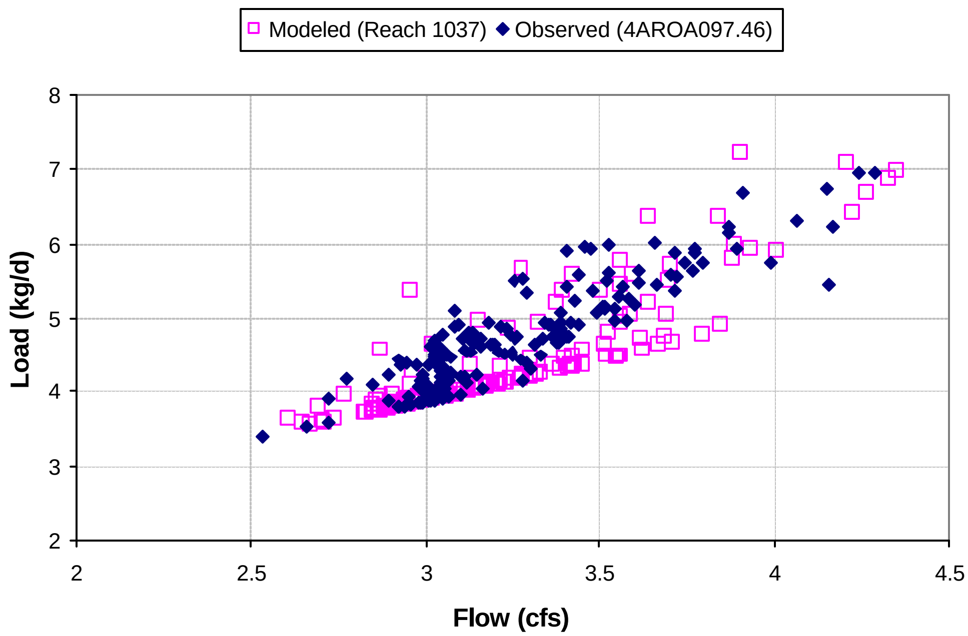

Figure F-5. Modeled vs. Observed Antilog Suspended Solids Loads (kg/d) at 4AROA097.46

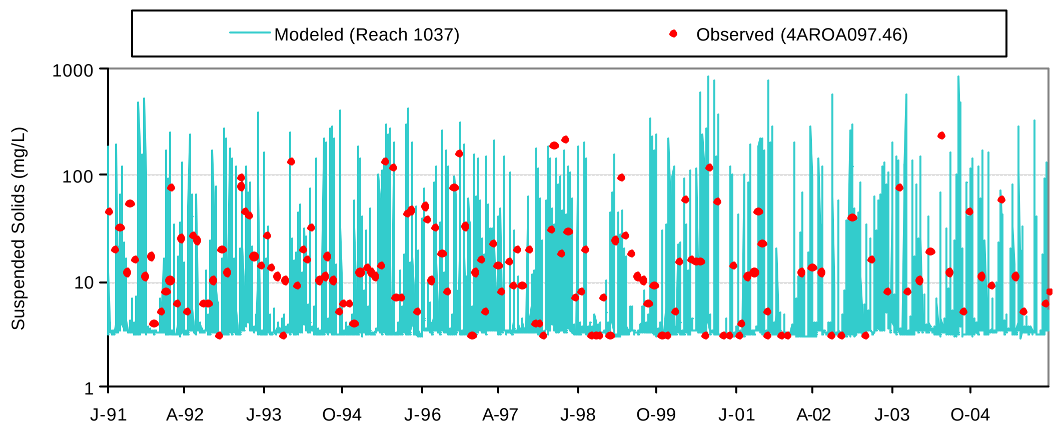

Figure F-6. Modeled vs. Observed Suspended Solids (mg/L) at 4AROA097.46

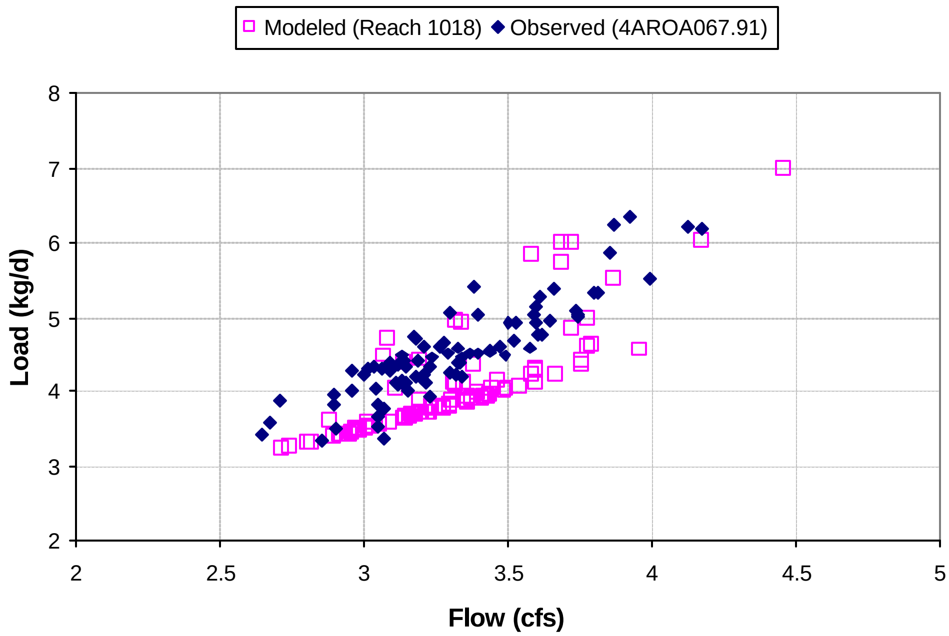

Figure F-7. Modeled vs. Observed Antilog Suspended Solids Loads (kg/d) at 4AROA067.91

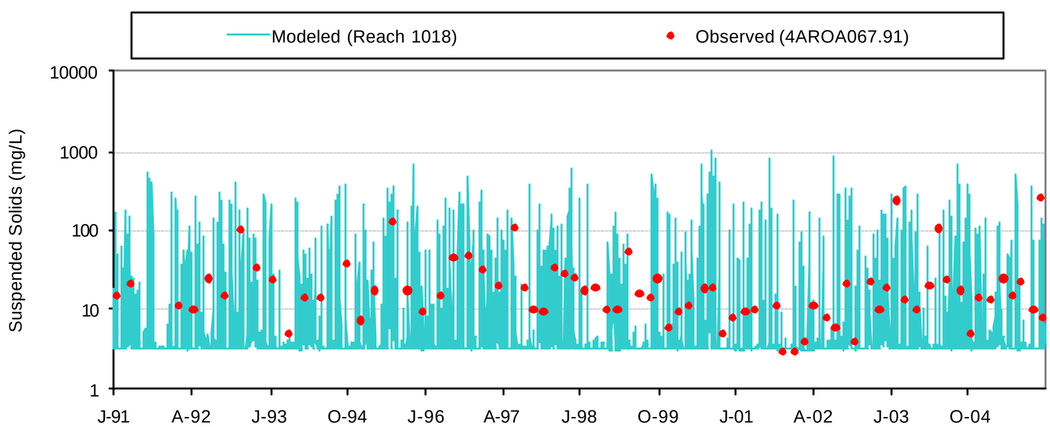

Figure F-8. Modeled vs. Observed Suspended Solids (mg/L) at 4AROA067.91

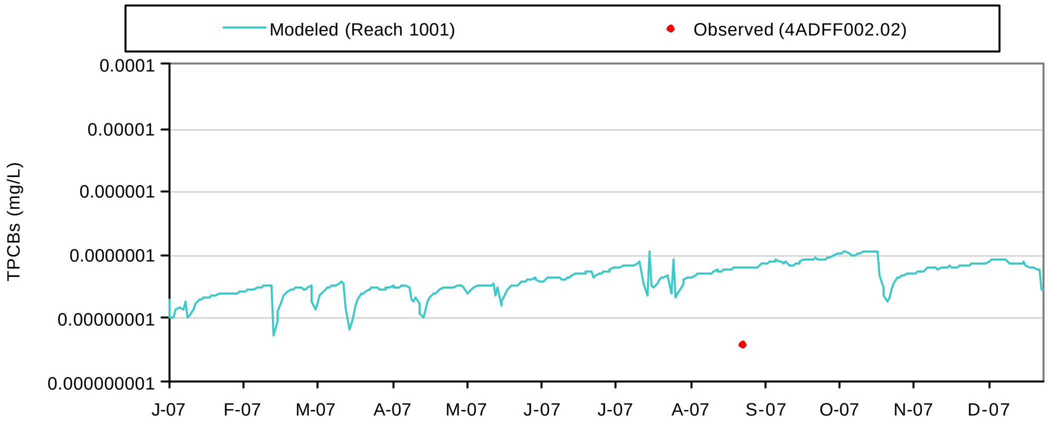

Figure F-9. Modeled vs. Observed TPCBs (mg/L) at 4ADFF002.02

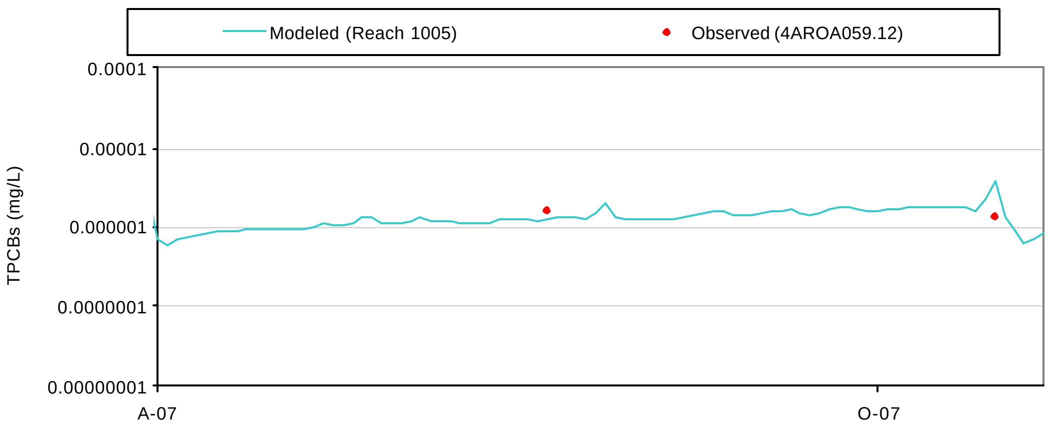

Figure F-10. Modeled vs. Observed TPCBs (mg/L) at 4AROA059.12

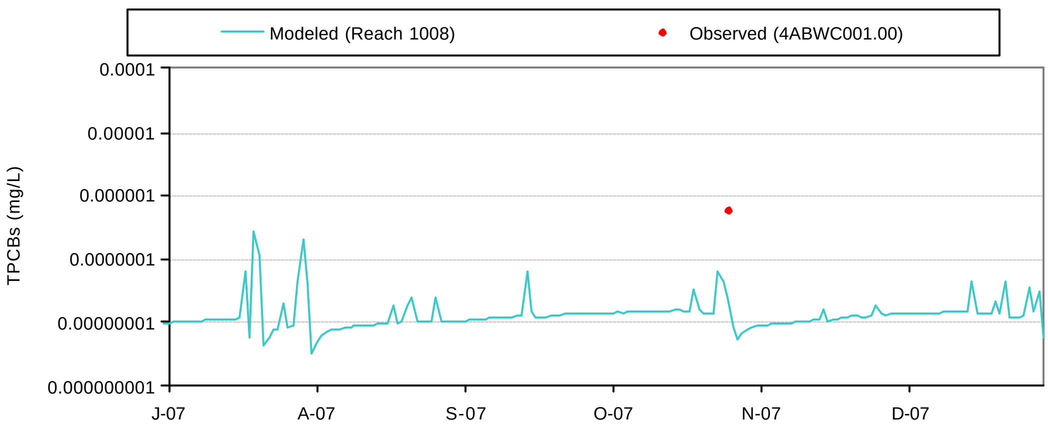

Figure F-11. Modeled vs. Observed TPCBs (mg/L) at 4ABWC001.00

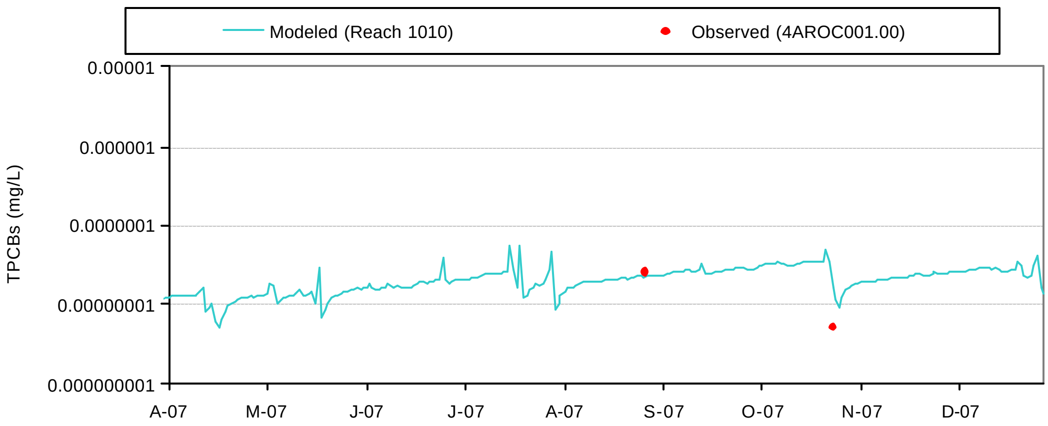

Figure F-12. Modeled vs. Observed TPCBs (mg/L) at 4AROC001.00

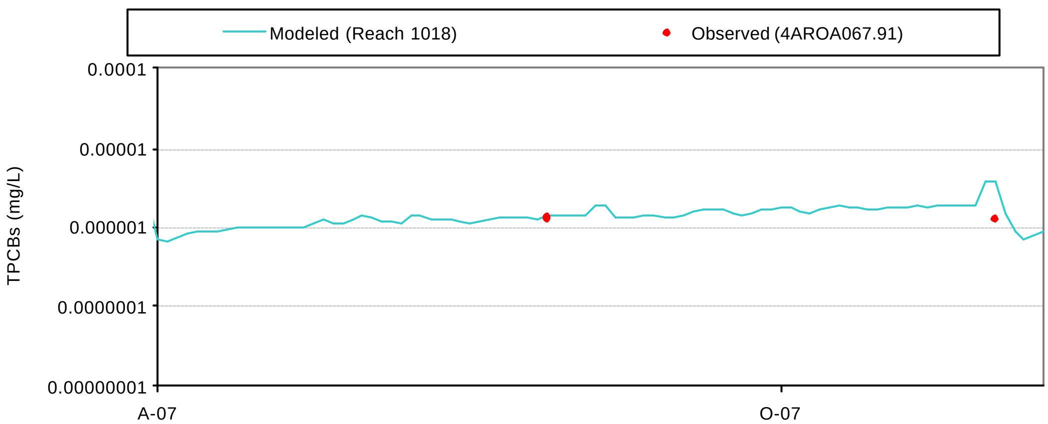

Figure F-13. Modeled vs. Observed TPCBs (mg/L) at 4AROA067.91

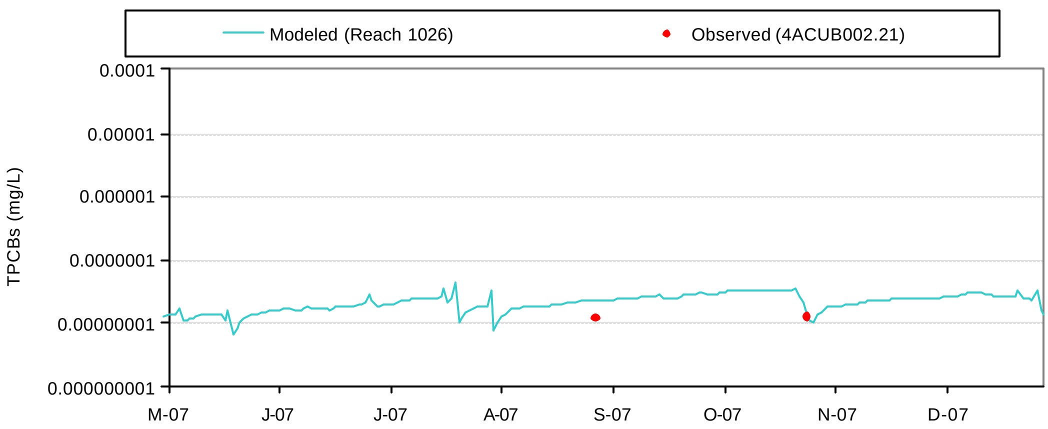

Figure F-14. Modeled vs. Observed TPCBs (mg/L) at 4ACUB002.21

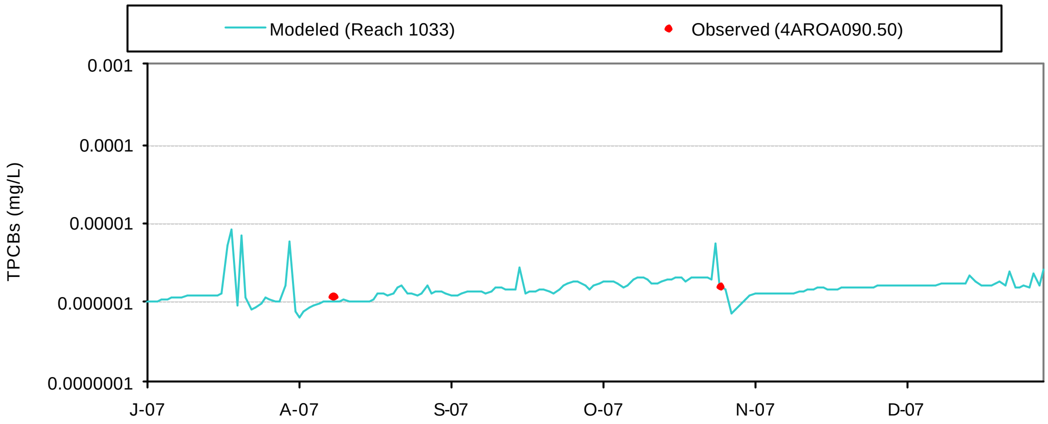

Figure F-15. Modeled vs. Observed TPCBs (mg/L) at 4AROA090.50

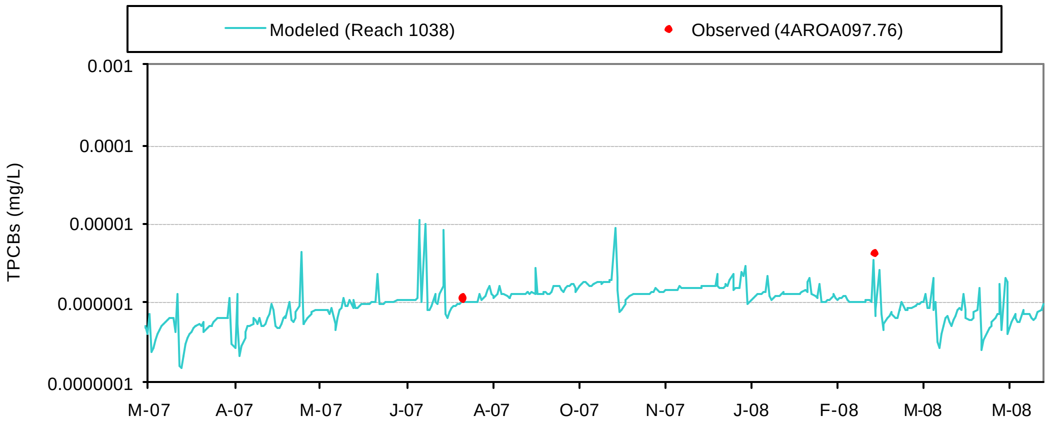

Figure F-16. Modeled vs. Observed TPCBs (mg/L) at 4AROA097.76

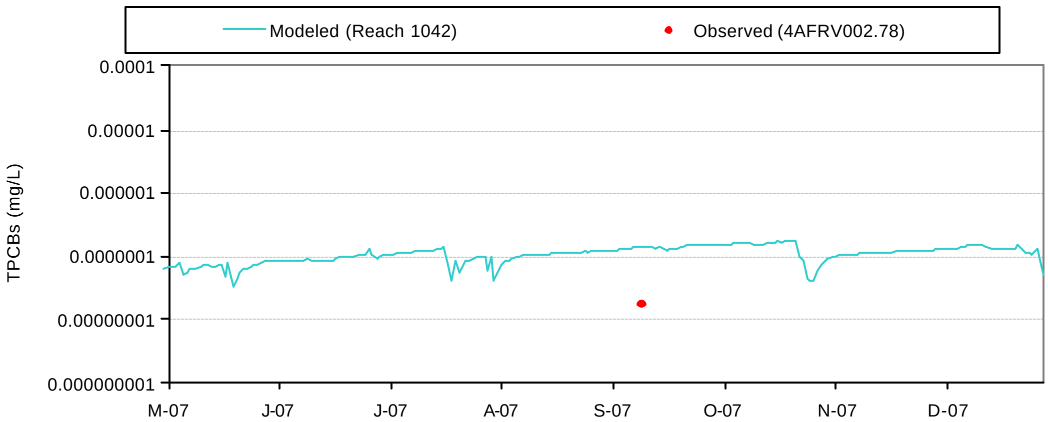

Figure F-17. Modeled vs. Observed TPCBs (mg/L) at 4AFRV002.78

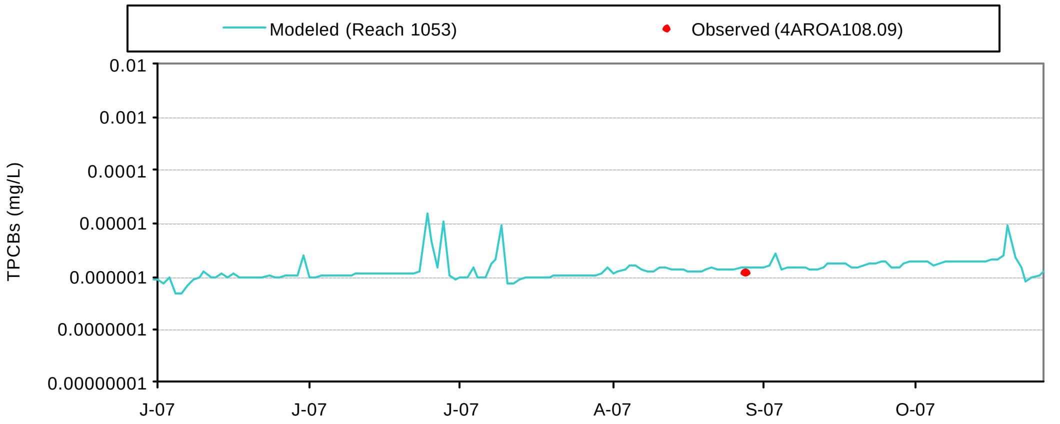

Figure F-18. Modeled vs. Observed TPCBs (mg/L) at 4AROA108.09

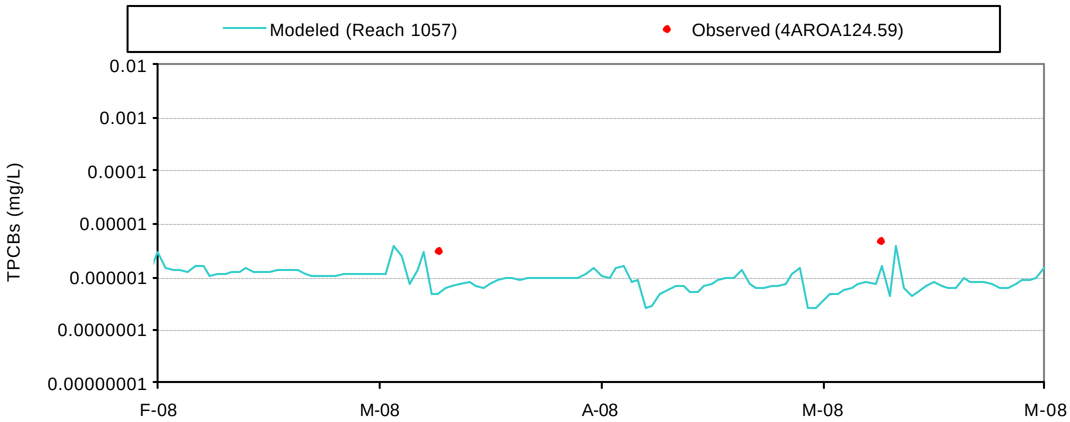

Figure F-19. Modeled vs. Observed TPCBs (mg/L) at 4AROA124.59

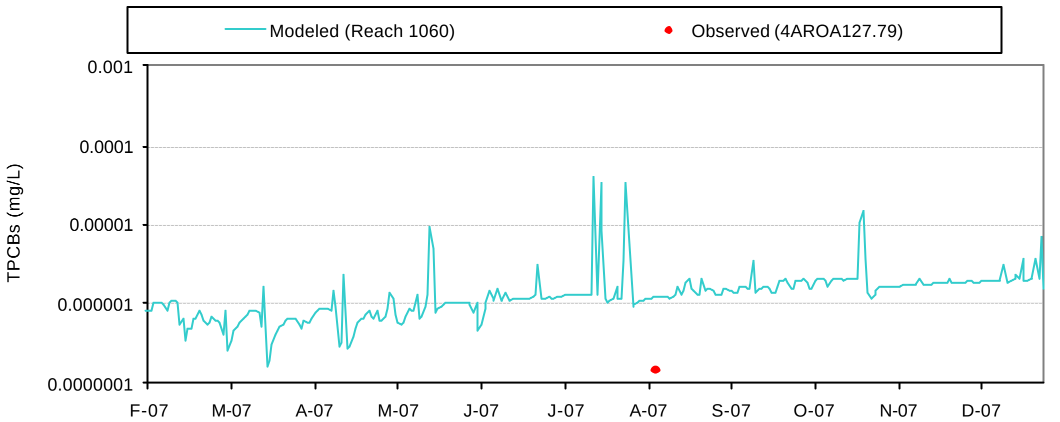

Figure F-20. Modeled vs. Observed TPCBs (mg/L) at 4AROA127.79

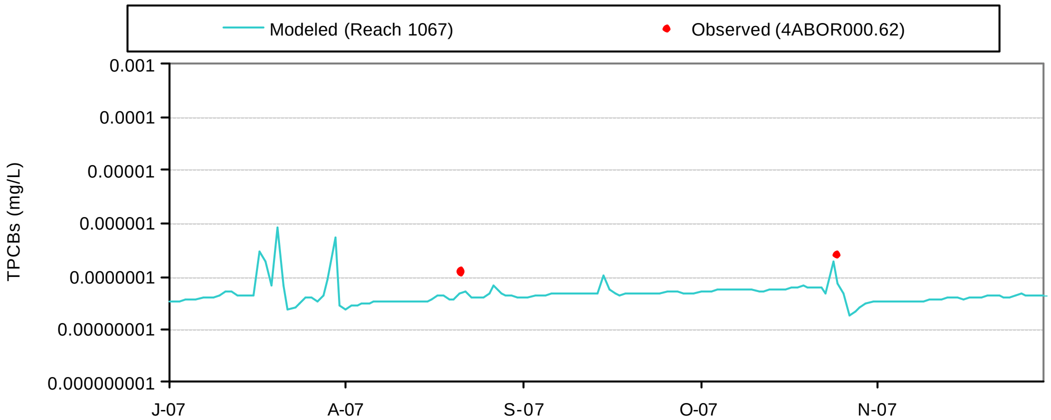

Figure F-21. Modeled vs. Observed TPCBs (mg/L) at 4ABOR000.62

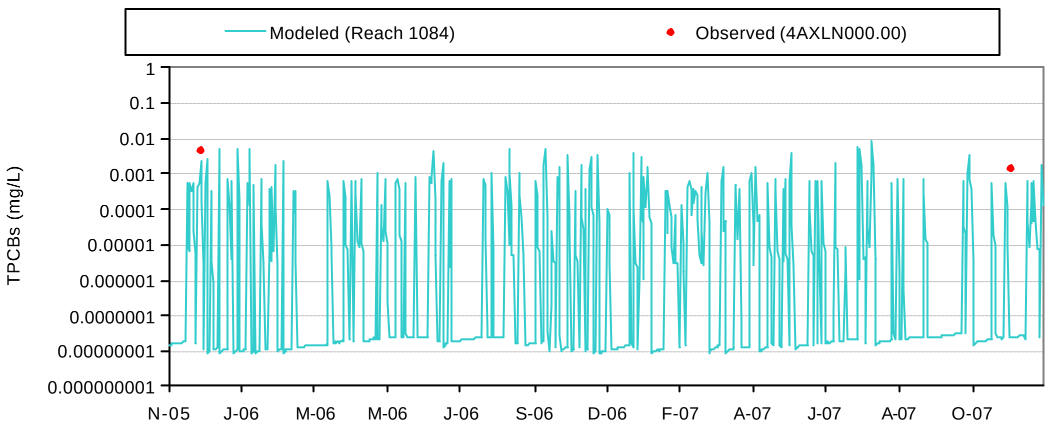

Figure F-22. Modeled vs. Observed TPCBs (mg/L) at 4AXLN000.00

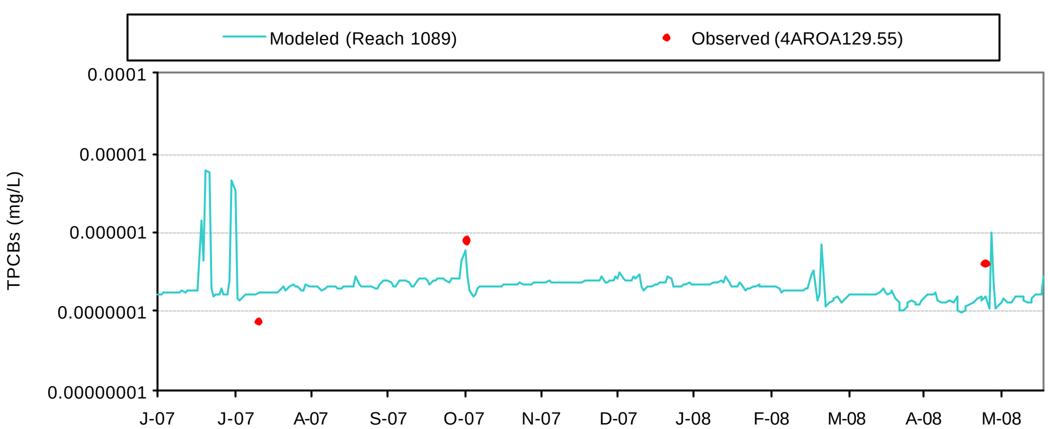

Figure F-23. Modeled vs. Observed TPCBs (mg/L) at 4AROA129.55

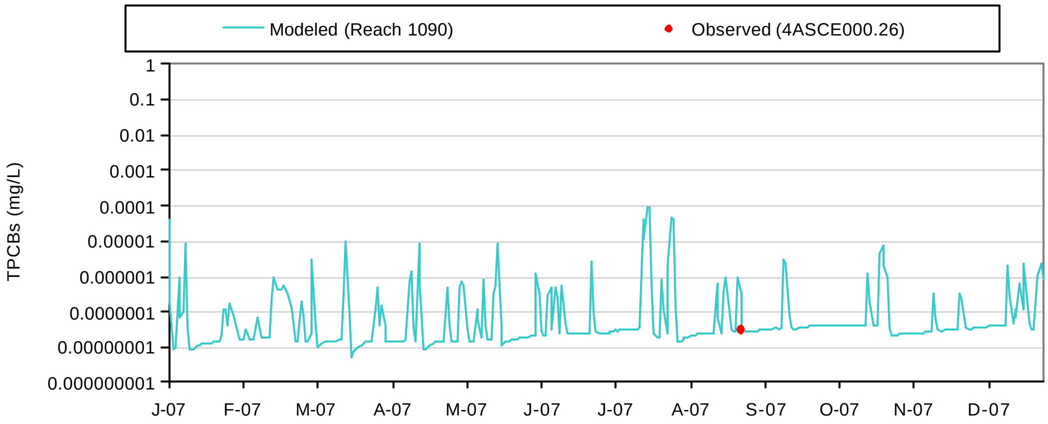

Figure F-24. Modeled vs. Observed TPCBs (mg/L) at 4ASCE000.26

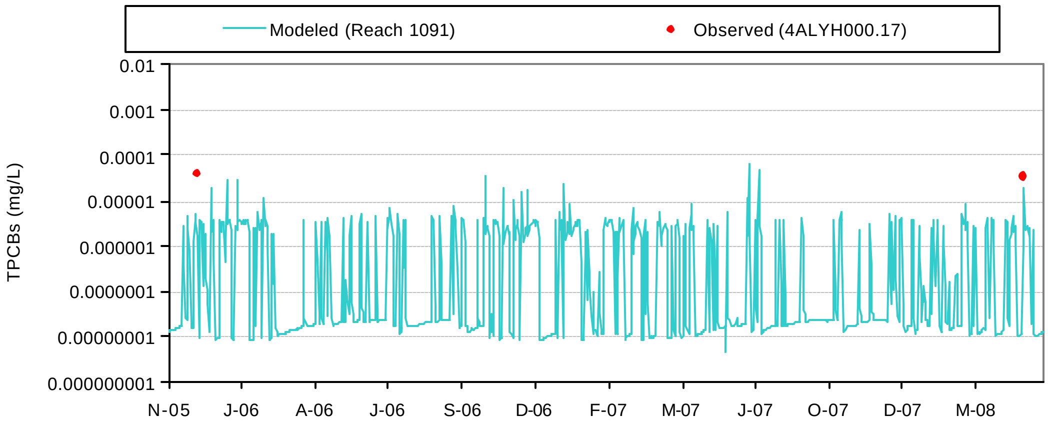

Figure F-25. Modeled vs. Observed TPCBs (mg/L) at 4ALYH000.17

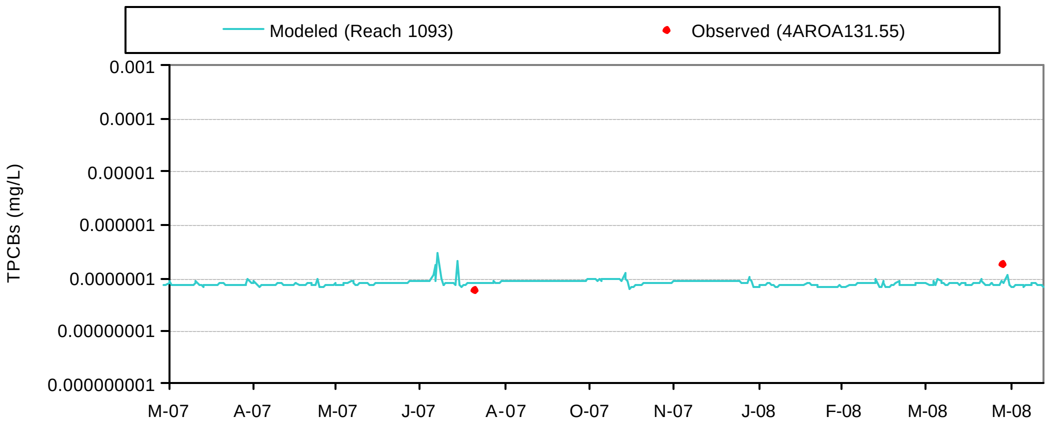

Figure F-26. Modeled vs. Observed TPCBs (mg/L) at 4AROA131.55

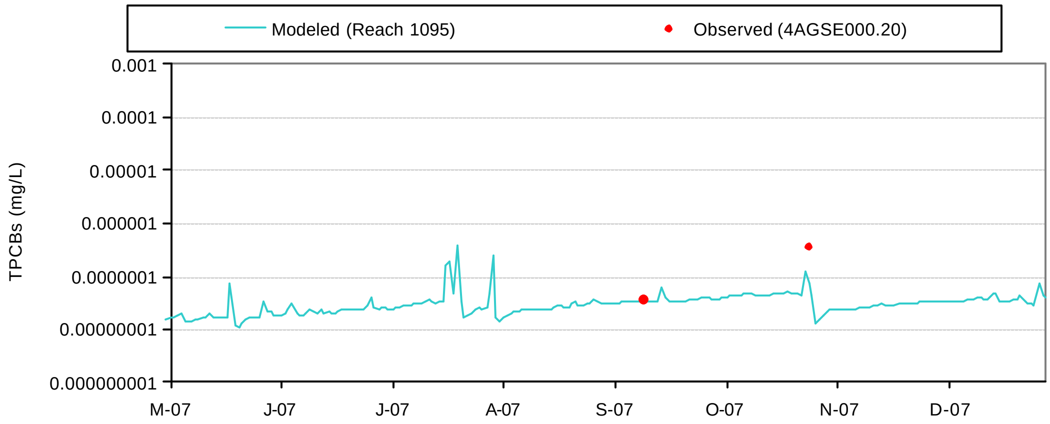

Figure F-27. Modeled vs. Observed TPCBs (mg/L) at 4AGSE000.20

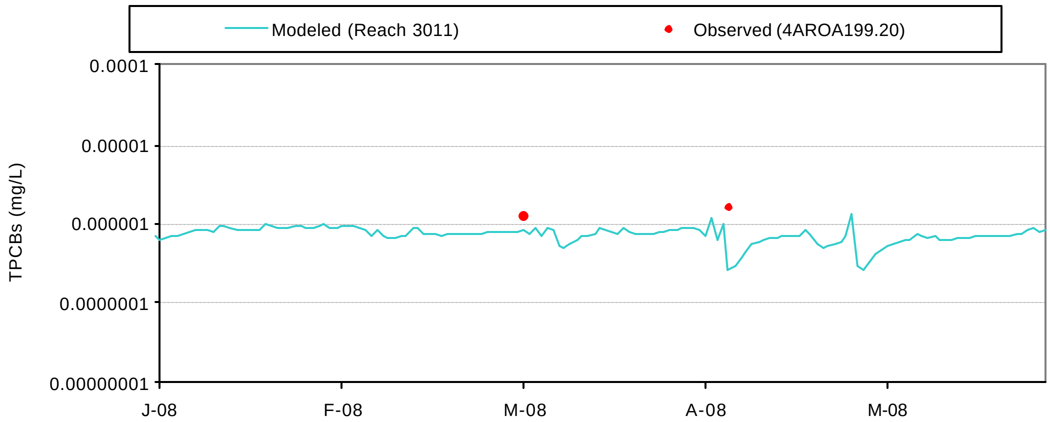

Figure F-28. Modeled vs. Observed TPCBs (mg/L) at 4AROA199.20

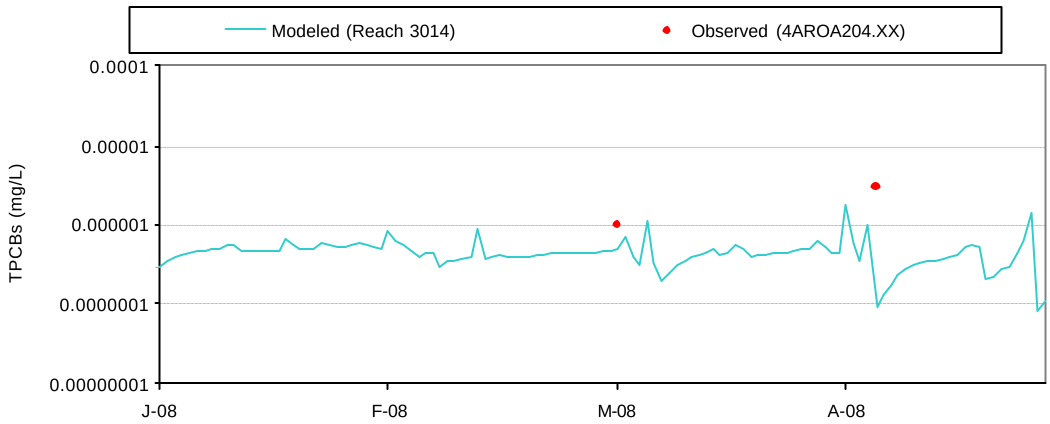

Figure F-29. Modeled vs. Observed TPCBs (mg/L) at 4AROA204.76

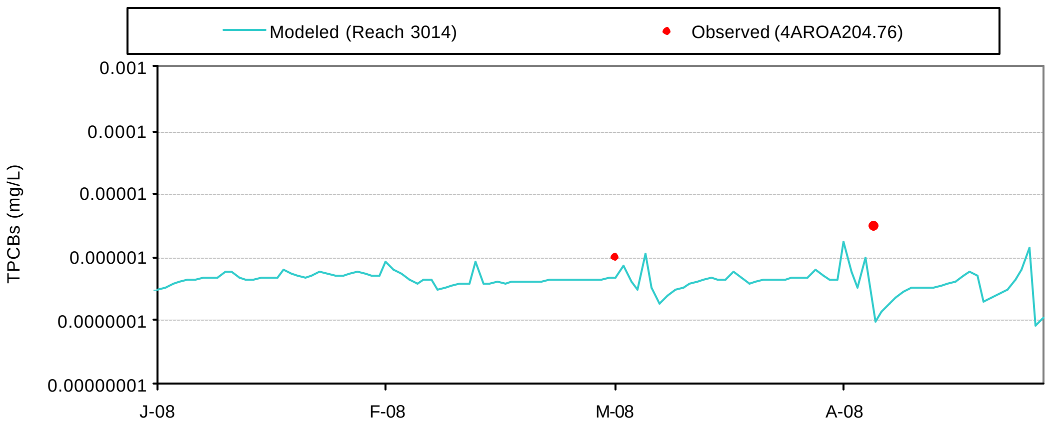

Figure F-30. Modeled vs. Observed TPCBs (mg/L) at 4AROA204.76

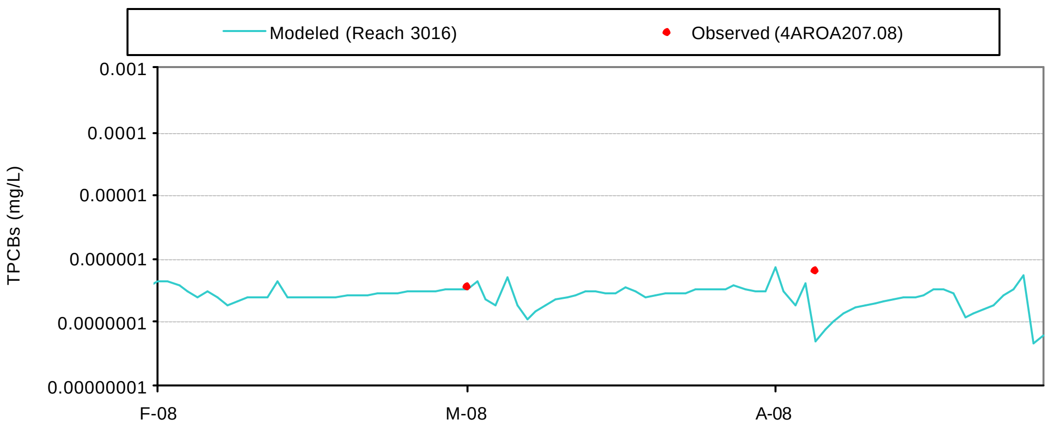

Figure F-31. Modeled vs. Observed TPCBs (mg/L) at 4AROA207.08

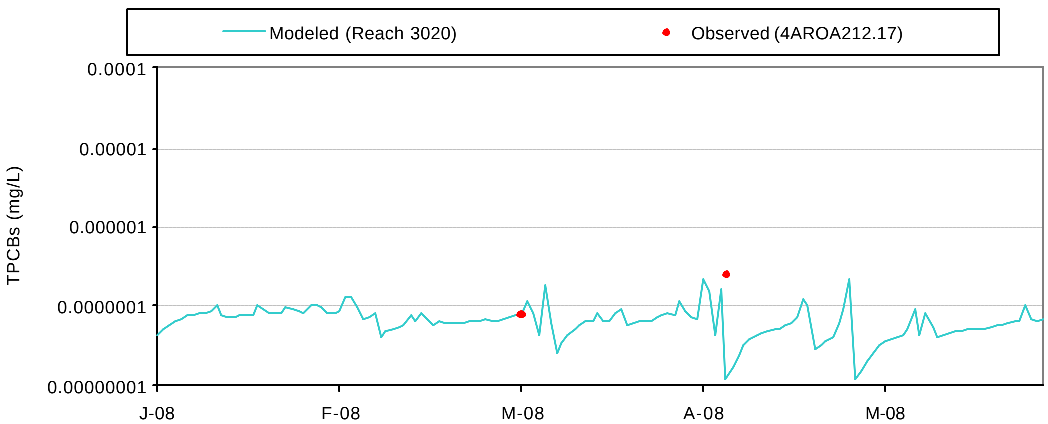

Figure F-32. Modeled vs. Observed TPCBs (mg/L) at 4AROA212.17

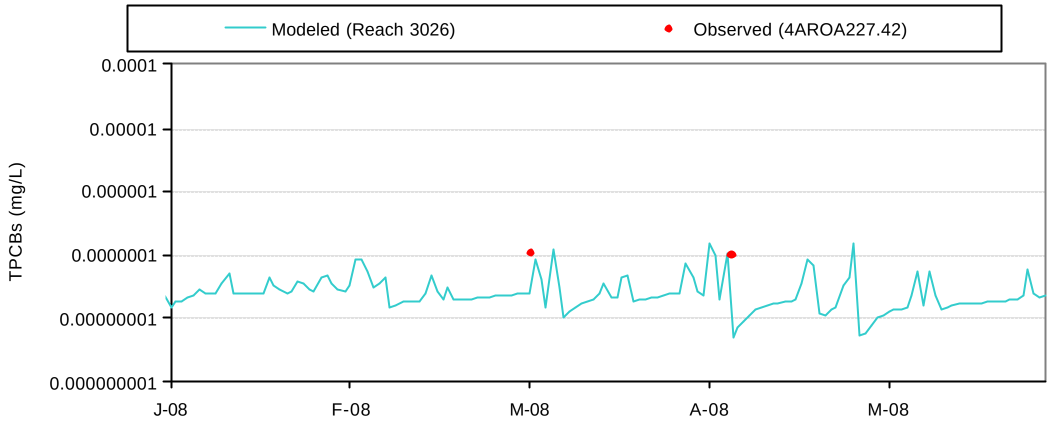

Figure F-33. Modeled vs. Observed TPCBs (mg/L) at 4AROA227.42

Appendix G:
TMDL Technical Approach and Model Setup

CONTENTS

TABLES

FIGURES

G1. TMDL TECHNICAL APPROACH

Establishing the relationship between the in-stream water quality targets and source loadings is a critical component of Total Maximum Daily Load (TMDL) development. It allows for evaluating management options that will achieve the desired source load reductions necessary to meet water quality standards. The link can be established through a range of techniques, from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. Ideally, the linkage will be supported by monitoring data that allow the TMDL developer to associate certain waterbody responses with flow and loading conditions.

This section presents the modeling approach for developing polychlorinated biphenyl (PCB) TMDLs for the Roanoke River basin. The objective of the Roanoke PCB TMDL study is to identify the sources of PCB contamination and to determine the reductions required to achieve water quality criteria for PCB impaired segments.

G1.1. Critical Considerations

The pollutant of concern for the current modeling application is total PCBs (tPCBs). PCBs are a hydrophobic, nonpolar, organic chemical species that tend to associate with fine sediments. PCBs associate with sediments by the process of adsorption. Adsorption describes the tendency of PCBs to accumulate on the surface of sediments in an aqueous environment as a function of energetic favorability, where the strength of the PCB-sediment association is proportional to the availability of adsorption surfaces [total suspended sediments (TSS) concentration], sediment organic content, and the PCB species degree of chlorination.

Land use in the Roanoke River basin includes extensive areas of largely undeveloped forest and pastoral lands and relatively small areas of concentrated development. Each land use affects the hydrology and sediment loads of the basin in a different way. Available monitoring data, as described in Section 2.2 of *Roanoke River PCB TMDL Development*, suggests that potential sources of PCBs are often associated with developed land uses.

Technical, regulatory, and stakeholder considerations informed the selection criteria for a watershed model to simulate PCB loading in the Roanoke River basin. On the basis of the considerations, the following factors were critical to selecting an appropriate watershed model. The model should do the following:

- Be able to represent the physical properties and loading and transport processes specific to the pollutant of concern (tPCBs)
- Be able to represent associated watershed processes critical to quantification of the pollutant of concern (TSS loading)
- Be able to address a watershed that has a combination of rural and urban land uses
- Be appropriate for simulating a large number of subwatersheds
- Provide adequate time-step estimation of flow and not oversimplify storm events to provide accurate representation of rainfall events/snowmelt and resulting peak runoff
- Be flexible enough to accommodate issues such as topography and meteorological variability over a large land area
- Be able to be calibrated and validated with the existing monitoring data
- Be able to be linked to an appropriate receiving water/lake model
- Be a sound platform for evaluating both existing baseline and hypothetical management decisions

- Be based on best available data and science
- Be nonproprietary, tested, and approved by the U.S. Environmental Protection Agency (EPA)
- Be adaptable and available for future applications

G1.2. Modeling Framework

A watershed modeling framework, consisting of the Loading Simulation Program C++ (LSPC) with sediment PCB modeling enhancements, was used to develop PCB TMDLs for the Roanoke River basin. A watershed model is a series of algorithms that integrate meteorological forcing data and watershed characteristics to simulate upland and tributary routing processes, including hydrology and pollutant transport. Once a model has been adequately set up and calibrated and the dominant unit processes are deemed representative on the basis of comparison with available monitored conditions, it becomes a useful tool to quantify existing flows and loads from tributaries without gages and from diffuse, overland flow sources.

G1.2.1. Loading Simulation Program C++ (LSPC)

On the basis of the considerations described above and previous modeling experience, EPA-approved LSPC (http://www.epa.gov/athens/wwqtsc/html/lspc.html) was selected for Roanoke River watershed modeling. LSPC is a watershed modeling system that includes Hydrologic Simulation Program–FORTRAN (HSPF) algorithms for simulating watershed hydrology, erosion, and water quality processes, as well as in-stream transport processes. During the past several years it has been used to develop hundreds of EPA-approved TMDLs, and it is generally considered the most advanced hydrologic and watershed loading model available.

LSPC integrates a geographic information systems (GIS), comprehensive data storage and management capabilities, the original HSPF algorithms, and a data analysis/post-processing system into a convenient, PC-based Windows environment. The algorithms of LSPC are identical to a subset of those in the HSPF model. EPA's Office of Research and Development in Athens, Georgia, maintains LSPC, and it is a component of EPA's National TMDL Toolbox (http://www.epa.gov/athens/wwqtsc/index.html). A brief overview of the HSPF model is provided below, and a detailed discussion of HSPF-simulated processes and model parameters is in the HSPF user's manual (Bicknell et al. 1997).

HSPF is a comprehensive watershed and receiving water quality modeling framework that was originally developed in the mid-1970s. The hydrologic portion of HSPF/LSPC is based on the Stanford Watershed Model (Crawford and Linsley 1966), which was one of the pioneering watershed models. The HSPF framework is composed of modules with components that can be assembled in different ways, depending on the objectives of the project. The model includes three major modules:

- PERLND for simulating watershed processes on pervious land areas
- IMPLND for simulating processes on impervious land areas
- RCHRES for simulating processes in streams and vertically mixed lakes

All three modules include many submodules that calculate the various hydrologic, sediment, and water quality processes in the watershed. Table G1-1 lists the modules from HSPF that are used in LSPC.

Table G1-1. HSPF modules included in LSPC

Receiving water modules (RCHRES)	HYDR	Simulates in-stream hydraulic behavior
	ADCALC	Simulates in-stream advection of dissolved or entrained constituents
	CONS	Simulates in-stream conservative constituents
	HTRCH	Simulates in-stream heat exchange
	SEDTRN	Simulates in-stream behavior of inorganic sediment
	GQUAL	Simulates in-stream behavior of a generalized quality constituent

Watershed modules PERLND/IMPLND	SNOW	Simulates snow fall, accumulation, and melting
	PWATER/IWATER	Simulates water budget for a pervious/impervious land segment
	SEDMNT/SOLIDS	Simulates production and removal of sediment for a pervious/impervious land segment
	PSTEMP	Simulates soil layer temperatures
	PWTGAS/IWTGAS	Estimates water temperature and dissolved gas concentrations in the outflows from pervious/impervious land segments
	PQUAL/IQUAL	Simulates water quality in the outflows from pervious/impervious land segments

Source: (Bicknell et al. 1997)

Spatially, the watershed is divided into a series of subbasins or subwatersheds representing the drainage areas that contribute to each of the stream reaches. These subwatersheds are then further subdivided into segments representing different land uses. For the developed areas, the land use segments are further divided into pervious (PERLND) and impervious (IMPLND) fractions. The stream network (RCHRES) links the surface runoff and subsurface flow contributions from each of the land segments and subwatersheds and routes them through the waterbodies using storage-routing techniques.

The stream-routing component considers direct precipitation and evaporation from the water surfaces, as well as flow contributions from the watershed, tributaries, and upstream stream reaches. Flow withdrawals and diversions can also be accommodated. The stream network is constructed to represent all the major tributary streams, as well as different portions of stream reaches where significant changes in water quality occur.

Important routines for water quality simulation include the QUAL and SED modules, both of which have PERLND/IMPLND and RCHRES components that define the upland and in-stream characteristics of each. Together, these routines provide the basic framework for simulating pollutant loading and transport in a watershed.

The QUAL module simulates the behavior of a generalized water quality constituent by linking land use surface runoff, associated pollutant loadings, and in-stream conditions. It allows for a constituent to be present in a dissolved or sediment-associated state, and in its simplest configuration, represents all transformations and removal processes using simple, first-order decay approaches. The framework is flexible and allows for different combinations of constituents to be modeled depending on data availability and the objectives of the study. When considering both the dissolved- and sediment-associated states, QUAL simulates the following processes:

- Advection
- Decay processes
- Deposition and scour of adsorbed material with sediment
- Adsorption/desorption between dissolved- and sediment-associated phases

The SED module simulates the production and transport of sediments. The parameterization of its upland component (SEDMNT) is closely related to the factors of the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978), while its in-stream component (SEDTRN) is highly dependant on the hydraulic characteristics of the model stream reaches.

The advantages of choosing LSPC as the watershed model for the Roanoke basin include the following:

- It simulates all the necessary constituents and applies to rural and urban watersheds.
- It allows for customization of algorithms and subroutines to accommodate the needs of the Roanoke River basin study, including the following:
    - Adsorptive/desorptive properties of PCBs
    - Deposition/resuspension of sediments

- The time-variable nature of the modeling enables a straightforward evaluation of the cause-effect relationship between source contributions and waterbody response, as well as direct comparison to relevant water quality criteria.
- It allows for the incorporation of Virginia Department of Environmental Quality (VADEQ) monitoring data.
- It has a comprehensive modeling framework that uses the proposed LSPC approach, thereby facilitating development of TMDLs not only for this project, but also for potential future projects to address other impairments throughout the Roanoke River basin.
- The proposed modeling tools are in the public domain and approved by EPA for use in TMDLs.
- The model includes both surface runoff and base flow (groundwater) conditions.
- It provides storage of all physiographic, point source/withdrawal data and process-based modeling parameters in a Microsoft Access database and text file formats to provide for efficient manipulation of data.
- It presents no inherent limitations with respect to the size and number of watersheds and streams that can be modeled.
- It provides flexible model output options for efficient post-processing and analysis designed specifically to support TMDL development and reporting requirements.
- It can be linked to a receiving water model.

G2. MODEL SETUP

An LSPC model was configured for the areas contributing to TMDL impaired streams (see Section 1.2 of *Roanoke River PCB TMDL Development*) in the Roanoke River basin as a series of hydrologically connected subwatersheds. Configuring the model involved subdividing the watersheds into modeling units, followed by continuous simulation of flow and water quality for the units using meteorological, land use, soils, stream, and water quality data. Developing and applying the watershed model to address the project objectives involved the following major steps:

1. Watershed Segmentation
2. Configuration of Key Model Components
3. Representation of Watershed Sources
4. Model Calibration and Validation

G2.1. Watershed Segmentation

Watershed segmentation refers to the subdivision of the entire watershed into small, discrete subwatersheds for modeling and analysis. Subwatersheds represent hydrologically connected modeling units and capture the drainage areas of their associated stream segments. The delineated subbasins represent the scale at which model simulations take place.

The Roanoke River watershed was divided into two separate segments for modeling purposes—the upper Roanoke, which extends from its headwaters downstream to Niagra Dam, and the lower Roanoke (Staunton), which includes the length of the River from Leesville Dam downstream to its confluence with the Dan River. These large segments were further subdivided into subbasins primarily using the watershed stream network, locations of tPCB sources, and topographic variability, and secondarily using the locations of available water quality, fish tissue, and sediment tPCB monitoring stations; the locations of U.S. Geological Survey (USGS) continuous stream flow gages; and existing watershed boundaries [Virginia subwatersheds (VAWATBOD) developed by VADEQ]. Delineation of the Roanoke River watershed resulted in 45 and 107 model subwatersheds for the upper and lower Roanoke (Staunton) segments, respectively (Figures G2-1 and G2-2).

The middle Roanoke, which includes the drainage area of the Roanoke River mainstem beginning just downstream of Niagra dam and extending downstream to Leesville Lake, is *not* considered in these TMDLs because its waters are outside the scope of the tPCB-impairment listings that are under investigation. Smith Mountain Lake and Leesville Lake are concurrent reservoirs with outflows managed for generating electricity, including pump-back operations. The middle segment includes two major tributaries to the reservoirs, the Blackwater and Pigg rivers. The model subbasin delineation includes those areas; therefore, the middle section can be included in future modeling updates for the Roanoke River watershed if needed for TMDL development or other purposes.

The two modeled segments include the waters designated as impaired for tPCBs on Virginia's 1998 303(d) list. Because there is no dynamic link between the two, to accurately represent the lower Roanoke (Staunton), discharge data from the Leesville Dam, which represents all upstream flows and pollutant load contributions to that point on the River, were incorporated as a model boundary condition. Hourly discharge data for the Leesville Dam were obtained from its operator, American Electric Power (AEP), and summarized as daily average values for model input. The average daily discharge time series used as the model boundary condition is in Appendix D.

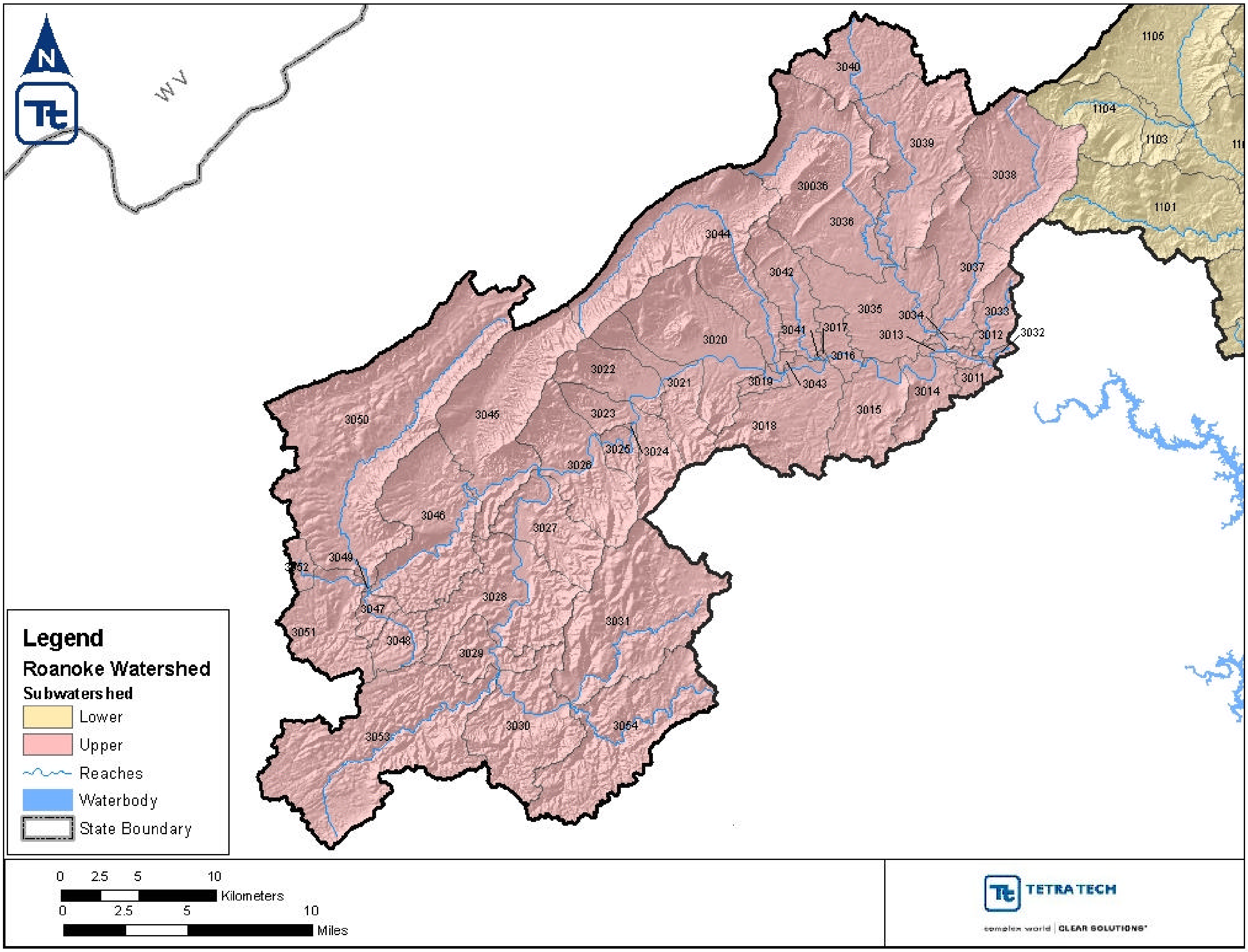

Figure G2-1. Subwatershed divisions of the upper Roanoke.

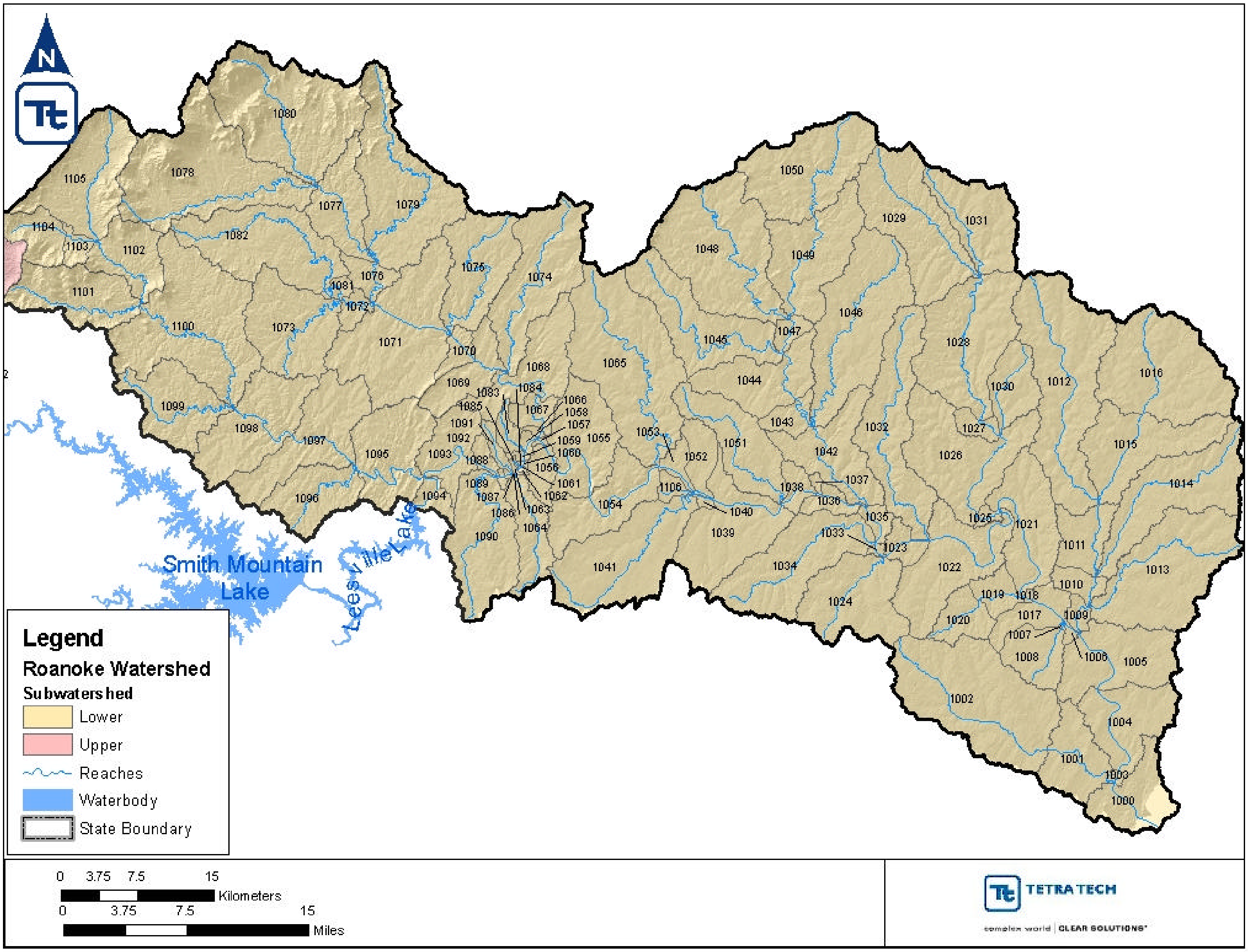

Figure G2-2. Subwatershed divisions of the lower Roanoke (Staunton).

G2.2. Configuration of Key Model Components

Configuring the model involved considering three major components, all of which provide the basis for the model's ability to estimate stream flow:

- Meteorological data, which drives the watershed model
- Land use representation, which provides the basis for distributing soils and pollutant loading characteristics throughout the basin
- Watershed physical attributes, which provide the basis for estimating stream channel geometry

G2.2.1. Meteorology

Hydrologic processes depend on changes in environmental conditions, particularly weather. As a result, meteorological data are a critical component of the watershed model. Such data are the driver of LSPC algorithms simulating watershed hydrology and water quality; thus, accurately representing climactic conditions is required to develop a valid modeling system.

The climate data requirements of the model vary depending on whether processes related to snowfall are represented. If snowfall is omitted from the simulation, precipitation (rainfall) and evapotranspiration are the only data needed. When snow is included, dry bulb air temperature, wind speed and direction, solar radiation, and dew point temperature are also required. Snowfall was included in the TMDL model setup because it is a significant component of the precipitation totals in the Roanoke River basin. Seasonal snowfall, accumulation, and melt affect the timing and magnitude of watershed stream flows.

Key meteorological data were accessed from the National Oceanic and Atmospheric Administration's National Climatic Data Center (NCDC) to develop a representative data set for the study area covering the modeling period. NCDC stores and distributes weather data gathered by the Cooperative Observer Network (COOP) and Weather Bureau Army-Navy (WBAN) airways stations throughout the United States. COOP stations record hourly or daily rainfall data, while airways stations record various climactic data at hourly intervals, including rainfall, temperature, wind speed, dew point, humidity, and cloud cover.

Rainfall and other meteorological data are taken directly from NCDC station records. Required climactic data not included in the NCDC records—evapotranspiration and solar radiation—were calculated from the available data using literature methodologies (Hamon 1961). All meteorological data were subsequently formatted for use as hourly time-series. An hourly time step is required to properly reflect diurnal temperature changes and provide adequate resolution for rainfall/runoff intensity to drive water quality processes during storms or snowmelt events.

Identifying the most representative weather data for the model was done using several factors, including geographic coverage, data record, and data completeness. Tables G2-1 and G2-2 list the selected daily COOP and WBAN stations and the completeness of the record expressed as the percentage of the data set not missing as reported by NCDC. Figure G2-3 presents the weather station locations.

Table G2-1. WBAN climate stations

WBAN ID	Elevation (ft)	Parameter	Period of record	% Complete
13733	940	Precipitation (in)	01/01/1979–5/31/2008	97%
		Dewpoint Temp (°F)	01/01/1979–5/31/2008	97%
		Dry-Bulb Temp (°F)	01/01/1979–5/31/2008	100%
		Wind Speed (mph)	01/01/1979–5/31/2008	99%
13741	1,149	Precipitation (in)	01/01/1979–5/31/2008	100%
		Dew point Temp (°F)	01/01/1979–5/31/2008	100%
		Dry-Bulb Temp (°F)	01/01/1979–5/31/2008	100%
		Wind Speed (mph)	01/01/1979–5/31/2008	100%

Table G2-2. COOP precipitation stations

ID	Station name	Elevation (ft)	Period of record	% Complete
440766	Blacksburg NWSO	2,100	11/01/1952–12/31/2005	96%
441121	Buchanan	880	01/01/1930–12/31/2005	94%
441692	Christianburg	2,100	08/01/1995–12/31/2005	95%
444148	Huddleston 4 SW	1,045	09/02/1950–12/31/2005	98%
444568	Keysville 2 S	530	09/01/1979–12/31/2005	86%
444676	Lafayette 1 NE	1,320	06/01/1951–12/31/2005	98%
445120	Lynchburg WSO Airport	940	01/01/1930–12/31/2005	92%
447285	Roanoke WSO Airport	1,149	08/01/1948–12/31/2005	98%

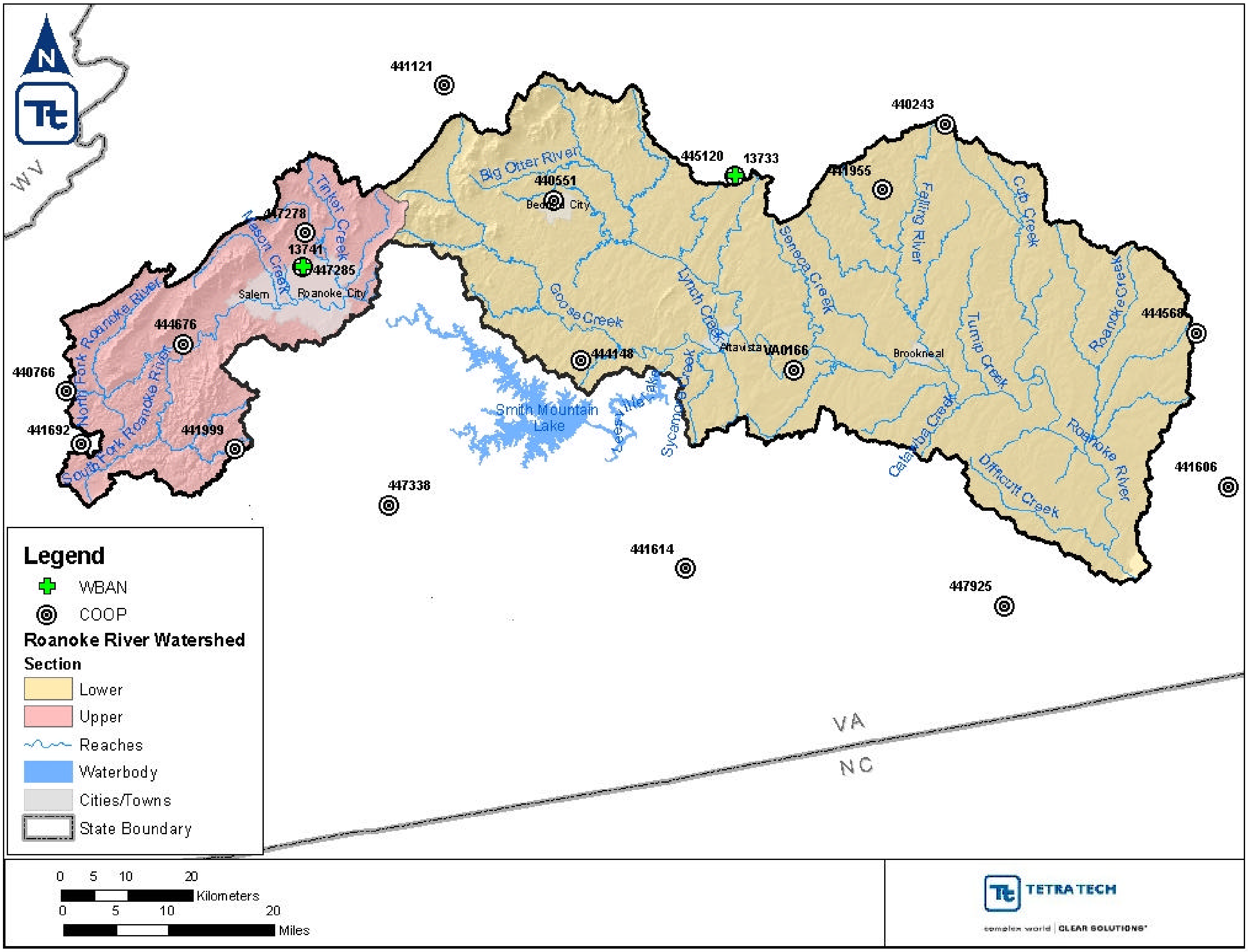

Figure G2-3. Weather stations near the Roanoke River watershed.

The data obtained were subjected to a quality assurance/quality control regime that identified gaps in data that could misrepresent observed conditions. An effort was made to select weather stations with a high level of completeness. However, data time series contain various intervals of accumulated, missing, or deleted data. In such cases, rainfall patching was performed to ensure proper representation. Patching involves using the *normal-ratio method*, which estimates a missing rainfall record with a weighted average from surrounding stations with similar rainfall patterns. Accumulated, missing, and deleted data records are repaired using hourly rainfall patterns at nearby stations with unimpaired data. Figure G2-4 presents an example of a patched precipitation time series with missing and accumulated data. Note that where no hourly data are available to disaggregate the accumulated data (February 13, 1994) a normal distribution is assumed.

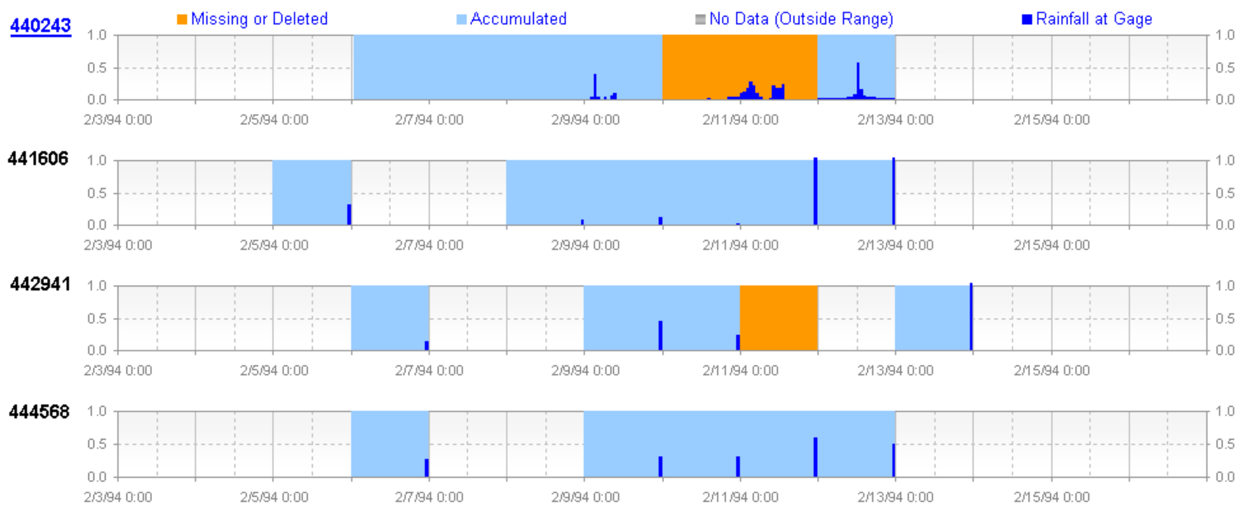

Figure G2-4. Example of a patched time series.

G2.2.2. Land Use and Soils Data

LSPC requires a basis for distributing hydrologic parameters. This is necessary to appropriately represent hydrologic variability throughout the watershed, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly correlated to land practices. The basis for this distribution was provided by land use and soils GIS data coverages for the watershed.

General land use/land cover data sets for the Roanoke River watershed were extracted from the National Land Cover Dataset (NLCD) database (MRLC 2001) (See Section 2.1.1 of *Roanoke River PCB TMDL Development*). NLCD data were derived from satellite imagery taken circa 2001 and provide detailed categorization of urban and natural areas. The detailed NLCD land cover descriptions were generalized for the model setup. Table G2-3 presents the original and grouped land uses used to characterize the watershed.

LSPC requires that land use categories be divided into separate pervious and impervious land units. This division was made for the appropriate land uses (urban) to represent impervious and pervious areas separately. The division was based on the impervious percentages description provided in the NLCD metadata.

Table G2-3. Model setup land use categories

Land use description	Group description	% Pervious	% Impervious
Open Water	Water/Wetland	100.0%	0.0%
Woody Wetlands		100.0%	0.0%
Herbaceous Wetlands		100.0%	0.0%
Pasture/Hay	Pasture	100.0%	0.0%
Grassland		100.0%	0.0%
Row Crops	Cropland	100.0%	0.0%
Deciduous Forest	Forest	100.0%	0.0%
Evergreen Forest		100.0%	0.0%
Mixed Forest		100.0%	0.0%
Shrub/Scrub		100.0%	0.0%
Barren Land	Other	100.0%	0.0%

Land use description	Group description	% Pervious	% Impervious
Developed, Open Space		100.0%	0.0%
Developed, Low Intensity	Developed	65.5%	34.5%
Developed, Medium Intensity		35.5%	64.5%
Developed, High Intensity		10.0%	90.0%

The Natural Resources Conservation Service (NRCS) has defined four hydrologic soil groups (Table G2-4 below) that classify soils according to their infiltration and runoff characteristics during periods of prolonged wetting (See Section 2.1.2 of *Roanoke River PCB TMDL Development*). Typically, clay soils (Group D) that are poorly drained have the lowest infiltration rates, while sandy soils (Group A) that are well drained have the highest infiltration rates. Data for the watershed were obtained from the State Soil Geographic Database (STATSGO) (USDA 1993) and were summarized by hydrologic soil groups.

Table G2-4. NRCS hydrologic soil groups

Hydrologic soils group	Description
A	Soils with high infiltration rates. Usually deep, well drained sands or gravels. Little runoff.
B	Soils with moderate infiltration rates. Usually moderately deep, moderately well drained soils.
C	Soils with slow infiltration rates. Soils with finer textures and slow water movement.
D	Soils with very slow infiltration rates. Soils with high clay content and poor drainage. High amounts of runoff.

Source: (USDA 1993)

The hydrologic soil groups were overlain with model grouped land uses to create a composite data layer that describes both land cover and soil group distribution in the watershed (Figure G2-5). The result is a composite layer that specifies the land use and soil group of an area at the resolution provided in the NLCD data layer (30 meters). The composite layer was used as the model land use allowing for the accurate representation of hydrologic variability at the subbasin level by taking into account both land surface and subsurface characteristics.

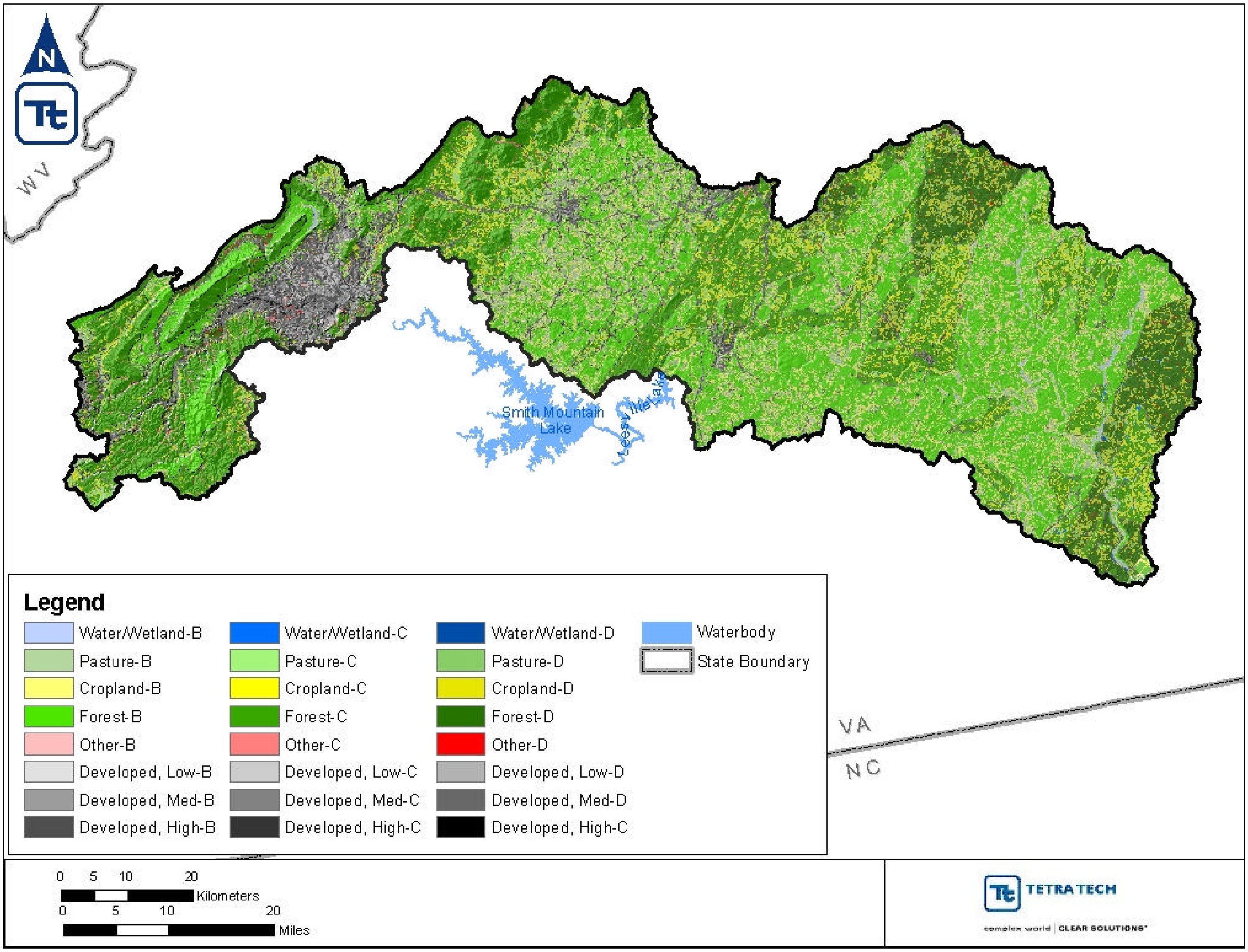

Figure G2-5. Composite model land use.

G2.2.3. Elevation Data/Stream Characteristics

LSPC requires a representative stream reach for each subwatershed to route flow throughout the subwatershed network. The stream network connects all the subwatersheds represented in the watershed model. Stream channels are assumed to be completely mixed, one-dimensional segments with a trapezoidal cross section. Stream channel bank-full widths and depth were estimated as a function of cumulative drainage area using the Rosgen stream cross-section coefficients for eastern North American streams (Rosgen 1994). LSPC automatically develops rating curves, referred to as function tables (FTABLES) in the model, for streams in the network using the defined channel cross sections. The FTABLE of a model stream reach defines its representative depth-outflow-volume-surface area relationship.

Watershed elevation data derived from the National Elevation Dataset (NED) (see Section 2.1.3 of *Roanoke River PCB TMDL Development*) was used to estimate stream channel slope (USGS 2009). In-stream flow calculations are made using the HYDR (hydraulic behavior simulation) module in LSPC, which is identical to the HYDR module in HSPF (Bicknell et al. 1997).

LSPC requires that each subwatershed representative stream reach be assigned to a stream class. A stream class defines the model parameters related to the simulation of in-stream pollutant transport and fate processes. A single stream class can be used to define these parameters for all representative stream reaches, or multiple stream classes can be defined in the model allowing parameter variability between stream reaches. For the Roanoke River LSPC model, an individual stream class was defined for each representative stream reach. This approach allowed a unique set of parameters to be assigned to each of the 152 reaches, 107 in the lower and 45 in the upper, corresponding to each model subwatershed.

G2.3. Source Representation

The Roanoke River PCB TMDL model considers TSS and PCB sources. Sources of TSS include nonpoint sources associated with the erosion and upland soils washoff and point source discharges from facilities. TSS sources are in the model setup because the representation of TSS point sources is required to accurately represent watershed hydrology, and nonpoint sediment loadings are the vehicle for sediment-associated tPCB loadings.

PCB sources are defined as either current or legacy as described in Section 3.0 of *Roanoke River PCB TMDL Development*. Both current and legacy sources are considered by the LSPC model representation of the Roanoke River basin. Current sources are point source dischargers, contaminated sites, urban background including unknown contaminated sites, and areas covered by general stormwater permits and municipal separate storm sewer systems (MS4s). All legacy sources are nonpoint and are composed of in-stream contaminated sediments and atmospheric deposition to surface waters. Available data were plotted in GIS and, as appropriate, assigned to the defined model subbasins, segments, and land uses.

Developing PCB TMDLs in the Roanoke River watershed is subject to adaptive implementation and ongoing source investigation whereby sources of tPCB contamination are continuously being reviewed and updated on the basis of the best available information. The following discussion of PCB sources, therefore, should be considered the most up-to-date information at the time these TMDLs were developed, rather than a complete and final characterization.

G2.3.1. TSS Sources

VADEQ provided an inventory of discharge monitoring reports (DMRs) for facilities permitted for point source discharges of TSS in the Roanoke River watershed. There are 52 facilities representing 55 outfalls in the Roanoke River watershed that are permitted for discharging TSS loads. Effluent from such facilities is represented at the rate and concentrations presented in the DMRs, where available, or at design flow and concentration limits where records were unavailable. Tables G2-5 and G2-6 present the National Pollutant Discharge Elimination System (NPDES) IDs, names, receiving water, design flow, and average concentration limit for facilities in the upper and lower model segments, respectively.

Table G2-5. Model TSS point sources—Upper Roanoke model segment

Facility name	NPDES ID	Outfall	Design flow (mgd)	Receiving stream	Avg. conc. limit (mg/L)
Roanoke City - Falling Creek	VA0001465	001	0	Falling Creek	30
Roanoke City - Carvins Cove Water Filtration Plant	VA0001473	001	0	Carvins Creek, unnamed tributary 1	30
Roanoke City - Carvins Cove Water Filtration Plant	VA0001473	002	0	Carvin Creek unnamed tributary 2	30
Roanoke City - Carvins Cove Water Filtration	VA0001473	003	0	Carvin Creek	30

Facility name	NPDES ID	Outfall	Design flow (mgd)	Receiving stream	Avg. conc. limit (mg/L)
Plant				unnamed tributary 2	
Steel Dynamics	VA0001589	005	0.039	Peters Creek	No limit
Norfolk Southern Railway Co - Shaffers Crossing	VA0001597	002	0	Lick Run unnamed tributary	30
Shawsville Town - Sewage Treatment Plant	VA0024031	001	0.2	South Fork Roanoke River	30
Western Virginia Water Authority Water Pollution Control Plant	VA0025020	001	42	Roanoke River	2.5
Blacksburg Country Club Sewage Treatment Plant	VA0027481	001	0.035	North Fork Roanoke River	30
Montgomery County PSA - Elliston-Lafayette Waste Water Treatment Plant	VA0062219	001	0.25	South Fork Roanoke River	30
Oak Ridge MHP Sewage Treatment Plant	VA0072389	001	0.015	Falling Creek unnamed tributary	30
Roanoke Moose Lodge	VA0077895	001	0.0047	Mason Creek	30
Crystal Springs Water Treatment Plant	VA0091065	001	0.092	Roanoke River	30

Table G2-6. Model TSS point sources—Lower Roanoke (Staunton) model segment

Facility name	NPDES ID	Outfall	Design flow (mgd)	Receiving stream	Avg. conc. limit (mg/L)
Motiva Enterprises LLC - Montvale	VA0001490	001	0.065	South Fork Goose Creek	No limit
Bedford City - Water Treatment Plant	VA0001503	001	0.038	Little Otter River unnamed tributary	30
Dan River, Inc – Brookneal	VA0001538	001	1.326	Roanoke (Staunton) River	No limit
ITG Burlington Industries, LLC, Hurt Plant	VA0001678	001	3.275	Roanoke River	No limit
Appomattox Trickling Filter Plant	VA0020249	001	0.17	Caldwells Creek	30
Altavista - Wastewater Treatment Plant	VA0020451	001	3.6	Roanoke River	30
Bedford County Schools - Liberty High School	VA0020796	001	0.024	Little Otter River unnamed tributary	30
Bedford County Schools - Body Camp Elem. School	VA0020818	001	0.005	Wells Creek unnamed tributary	30
Bedford Co - New London Academy	VA0020826	001	0.006	Buffalo Creek unnamed tributary	30
Bedford Co - Otter River Elem. School	VA0020851	001	0.005	Big Otter River unnamed tributary	30
Bedford County Schools - Thaxton Elem. School	VA0020869	001	0.004	Wolf Creek unnamed tributary	30
Brookneal - Staunton River Lagoon	VA0022241	001	0.078	Roanoke (Staunton) River	45
Brookneal - Falling River Lagoon	VA0022250	001	0.082	Falling River	30
Bedford City - Sewage Treatment Plant	VA0022390	001	2	Little Otter River	30
Halifax County Schools Clays Mill Elem. School	VA0022748	001	0.0072	Mill Branch unnamed tributary	30
DOC Rustburg Correctional Unit 9	VA0023396	001	0.028	Button Creek unnamed tributary	30
Moneta Adult Detention Facility	VA0023515	001	0.021	Mattox Creek unnamed tributary	30
Campbell Co Util and Serv Auth - Rustburg	VA0023965	001	0.2	Molley Creek	30
Keysville Waste Water Treatment Plant	VA0024058	001	0.5	Ash Camp Creek	30
Charlotte County Schools Bacon District Elem. School	VA0029319	001	0.006	Little Horsepen Creek unnamed tributary	30
Charlotte County Schools Phenix Elem. School	VA0029335	001	0.006	Terrys Creek unnamed tributary	30
Briarwood Village Mobile Home Park Sewage Treatment Plant	VA0031194	001	0.024	Smith Branch unnamed tributary	30
BP Products North America Incorporated	VA0054577	001	0	South Fork Goose Creek	No limit

Facility name	NPDES ID	Outfall	Design flow (mgd)	Receiving stream	Avg. conc. limit (mg/L)
BP Products North America Incorporated	VA0054577	003	0	South Fork Goose Creek unnamed tributary	No limit
Magellan Terminals Holdings LP - Montvale Terminal	VA0055328	001	0.008	South Fork Goose Creek unnamed tributary	No limit
Camp Virginia Jaycees Sewage Treatment Plant	VA0060909	001	0.015	Day Creek unnamed tributary	30
Charlotte County Schools Jeffress Elem. School	VA0063118	001	0.004	Sandy Creek unnamed tributary	30
Southern Mobile Home Park	VA0063568	001	0.0096	Piney Creek unnamed tributary	30
Bedford County Schools - Staunton River High School	VA0063738	001	0.026	Shoulder Run unnamed tributary	30
Thousand Trails Lynchburg Preserve	VA0068543	001	0.0396	Mollys Creek	30
Clover Waste Water Treatment Plant	VA0073733	001	0.035	Clover Creek	30
Woodhaven Nursing Home - Montvale	VA0074870	001	0.005	South Fork Goose Creek unnamed tributary	30
Campbell Co Utility and Service Authority - Otter River Water Filtration Plant	VA0078646	001	0.0428	Big Otter River	30
Alum Springs Shopping Center	VA0078999	001	0.04	Buffalo Creek	30
Old Dominion Electric Cooperative Clover	VA0083097	001	1.735	Roanoke River	30
Dominion - Pittsylvania Power Station	VA0083399	001	0.192	Roanoke River	30
Brookneal Town Water Treatment Plant	VA0084034	001	0.0006	Phelps Creek	30
Drakes Branch Waste Water Treatment Plant	VA0084433	001	0.08	Twitty's Creek	30
Montvale Wastewater Treatment Plant	VA0087238	001	0.05	South Fork Goose Creek	30
Dillons Trailer Park - Sewage Treatment Plant	VA0087840	001	0.018	Poorhouse Creek	55
Cedar Rock Waste Water Treatment Plant	VA0091553	001	0.015	Elk Creek unnamed tributary	30
Moneta Regional Waste Water Treatment Plant	VA0091669	001	0.5	Hunting Creek	30

G2.3.2. PCB Sources

Current Sources

The 12 point sources and 21 nonpoint sources described in Section 3.0 of *Roanoke River PCB TMDL Development* are represented as current PCB sources in the model. In addition to the known current sources, urban land areas throughout the model watershed have been assigned a level of contamination to account for unknown contaminated sites. Such areas are referred to as *urban background/unidentified* sources for the purposes of this TMDL.

Nonpoint Sources

The LSPC model was set up to represent nonpoint source loading of PCBs as a sediment-associated process. The sediment loads are simulated as a function of precipitation events and model parameters describing the erosive properties of model land uses. These loadings are the vehicle by which tPCBs are transported to waterbodies. For the representation of known contaminated sites, a PCB-contaminated land use was created. Using estimates of site footprints and locations, PCB land use areas were assigned to model subbasins. To maintain the sediment loading calibration presented in Section G2.7.3, a PCB land use category was created for each general land use with identical model sediment and hydrologic parameters (PCB-pasture, PCB-forest, PCB-urban, and others). The areas of PCB land uses are shown in Figures G3-2 through G3-4 of *Roanoke River PCB TMDL Development*.

Sites known to have PCB-contaminated soils were delineated into parcels as depicted in available aerial photography and USGS topoquads to estimate the contamination footprint. General model land use areas within the footprint were converted to corresponding PCB land uses and assigned a soils total PCBs (tPCBs) concentration, or *potency factor*, on the basis of available monitoring data. The soils monitoring data from the literature sources listed in Section 3.1 of *Roanoke River PCB TMDL Development* were used to estimate potency factors for known contaminated sites. A potency factor calculated from available sediment monitoring was also assigned to the remaining land areas in the watershed to capture loadings from unidentified contaminated sites. The following discussion does not apply to such areas.

The available soils monitoring data was aggregated and analyzed to establish trends that could be used to generalize model representation of PCB soils concentrations for nonpoint source land areas. The data suggest that two tiers of PCB land uses, moderately and highly contaminated areas, would be sufficient to capture the variability in soils contamination.

The LSPC model is set up to represent two separate land use parameter groups for the upper and lower Roanoke (Staunton) watershed sections. Though the land uses for the two sections are the same, they can be assigned independent parameter values. As a result, land uses for the upper and lower sections are, for modeling purposes, separate, giving unique moderately and highly PCB-contaminated areas for each. Therefore, the separation of the upper and lower Roanoke (Staunton) allows for four individual PCB land use potency factors [individual highly and moderately contaminated areas in the upper and lower Roanoke (Staunton)].

Two sites, BGF Industries and a hotspot within the contaminated site Virginia Scrap Iron Co., had median tPCBs soils concentrations of approximately 88 and 102 parts per million (ppm), respectively. The median concentration observed at those sites was at least two orders of magnitude greater than median concentrations measured at all other sites. BGF Industries is in the lower Roanoke (Staunton), while Virginia Scrap Iron Co. is in the upper. Thus, the median concentrations for each were used as the potency factors for highly contaminated areas in the respective sections. These are the only areas represented as highly contaminated in the model. Note that BGF Industries is permitted for stormwater discharges. The soils potency factor developed for the site was used characterize associated stormwater loads (see *Point Sources* in Section G2.3.2).

The tPCBs soils concentrations observed at the remaining contaminated sites were used to characterize moderate contamination. To derive potency factors for moderately contaminated areas, such sites were grouped according to the section of Roanoke in which they are located, and the associated potency factor was calculated as the mean soils concentration—1.8 and 2.4 ppm for upper and lower Roanoke (Staunton) sites, respectively. Table G2-7 lists the model-represented known contaminated sites and associated land area.

Table G2-7. Model PCB-contaminated sites

Site name	NPDES ID	County/city	Receiving stream	Area (acre)	Contamination level
A. O. Smith		Campbell	Roanoke (Staunton) River unnamed tributary	7.7	Moderate
Altavista STP	VA0020451	Campbell	Roanoke (Staunton) River	25.6	Moderate
American Viscose Co.		Roanoke City	Roanoke River	81.1	Moderate
Appalachian Power Co. (APCO) Yard		Roanoke City	Roanoke River	0.8	Moderate
BGF Industries[a]		Campbell	Roanoke (Staunton) River unnamed tributary	20.6	High
Burlington Industries-Altavista[a]	VA0001678	Pittsylvania	Sycamore Creek	116.3	Moderate
Dan River, Inc.	VA0001538	Campbell	Roanoke (Staunton)	37.7	Moderate

Site name	NPDES ID	County/city	Receiving stream	Area (acre)	Contamination level
			River		
Dixie Caverns Landfill	VAD980552095 [b]	Roanoke	Roanoke River	38.7	Moderate
East town Dump-Altavista		Campbell	Roanoke (Staunton) River	14.5	Moderate
English Construction		Pittsylvania	Roanoke (Staunton) River	12.0	Moderate
Evans Paint	VASFN0305570[b]	Roanoke City	Roanoke River	1.7	Moderate
Jacob Webb		Roanoke City	Roanoke River	5.5	Moderate
Lane Furniture Co.		Campbell	Roanoke (Staunton) River	49.6	Moderate
Norfolk Southern 1		Roanoke City	Roanoke River	2.5	Moderate
Norfolk Southern 2		Roanoke City	Roanoke River	64.3	Moderate
Oil distributors-Altavista		Campbell	Lynch Creek	5.7	Moderate
Roanoke River Floodway Bench Cuts		Roanoke	Roanoke River	47.4	Moderate
Schrader Bridgeport[a]		Campbell	Roanoke (Staunton) River unnamed tributary	16.0	Moderate
Tinker-American Electric Power (AEP) property		Roanoke City	Roanoke River	23.0	Moderate
Virginia Scrap Iron Co.	VRP408[c]	Roanoke City	Roanoke River	7.0	Moderate
				0.17	High
West town dump-Altavista		Campbell	Lynch Creek	28.0	Moderate

a. Where a contaminated site is covered by a stormwater permit, the source is considered a stormwater site for TMDL purposes (see *Point Sources* in Section G2.3.2)
b. EPA Superfund ID#
c. Virginia Voluntary Remediation Program (VRP) site#

Unidentified contaminated sites are represented in the model by a tPCBs potency factor assigned to urban land uses in the watershed. The available PCB sediment monitoring data record was used as a surrogate to estimate the PCB concentration of TSS loads from the areas. The sediment monitoring record was aggregated by watershed section, and the median concentration was assigned to generally represent the PCB concentration of upland soils. The potency factor calculated for the upper and lower sections, 6.8 and 4.9 parts per billion (ppb), are well below the currently applicable Toxic Substances Control Act PCB cleanup levels for high-occupancy areas (1 ppm) (USEPA 2005).

Point Sources

PCB point sources for the TMDLs include traditional facility effluent, MS4s, and sites permitted for stormwater discharges. VADEQ provided an inventory of the three types of point sources to be included in the Roanoke River watershed model. The methods used to represent PCB loads from those sources is discussed below.

Facilities found to be discharging PCB-contaminated effluent as part of the 2005–2008 Special Study monitoring are represented as PCB point sources in the model. Baseline tPCB loadings were derived using a mean effluent flow rate generated using Discharge Monitoring Reports (DMRs) and tPCB concentrations set at the mean concentration calculated from the Special Study data set. Several additional facilities that were not part of the Special Study were included as PCB point sources at the request of VADEQ. For the TMDL condition, the facility design flow was used along with the water quality target calculated for the watershed section in which the facility is located—390 picograms per liter (pg/L) for the upper and 140 pg/L for the lower—to represent facility tPCB loads. Facilities represented as PCB point sources and associated information including NPDES ID, mean monthly flow, and model represented effluent PCB concentration are presented in Table G2-8.

Table G2-8. Model PCB point source dischargers

NPDES facility name	Facility type	NPDES ID	Outfall	Mean mothly flow (cfs)	Mean PCB conc. (pg/L)
Dan River, Inc - Brookneal	Fabrics finishing	VA0001538	001	1.05	500
Steel Dynamics	Steel works	VA0001589	005	0.09	1,090
Norfolk Southern Railway Co - Shaffers Crossing	Railroads, line-haul operating	VA0001597	002	0.01	390
ITG Burlington Industries LLC Hurt Plant	Fabrics finishing	VA0001678	001	3.29	19,150
Altavista Town - Wastewater Treatment Plant	Sewerage systems	VA0020451	001	2.39	10,000
Brookneal Town - Staunton River Lagoon	Sewerage systems	VA0022241	001	0.07	140
Montgomery County PSA - Shawsville Sewage Treatment Plant	Sewerage systems	VA0024031	001	0.09	390
Western Virginia Water Authority Water Pollution Control Plant	Sewerage systems	VA0025020	001	57.78	340
Blacksburg Country Club	Sewerage systems	VA0027481	001	0.03	390
Montgomery County PSA - Elliston Lafayette Waste Water Treatment Plant	Sewerage systems	VA0062219	001	0.11	390
Old Dominion Electric Cooperative - Clover	Electric Services	VA0083097	001	1.16	190
Old Dominion Pittsylvania Power Station	Electric Services	VA0083399	001	0.17	140

VADEQ provided an inventory of MS4s and sites and facilities issued general permits for stormwater discharges in the Roanoke River basin. Such facilities are not subject to numerical criteria, but have responsibilities related to minimizing stormwater runoff and pollutant loads, and may be subject to monitoring requirements. Such areas are not represented explicitly in the model but are assigned PCB wasteload allocations in the TMDL. PCB loads for the areas are estimated as an area-weighted fraction of nonpoint source, land-use contributions with the PCB concentration represented by the appropriate potency factor.

Modeled land uses were overlain with GIS coverages of MS4s and sites covered by general stormwater permits to characterize the land use distributions of those areas. PCB loads for the permitted areas were calculated as the load generated by their respective land areas. Table G2-9 lists MS4s in the Roanoke River basin. Appendix C provides a list of sites and facilities covered by general stormwater permits. Loads from contaminated sites within the spatial extent of an MS4 or site permitted for stormwater are considered a component of the associated MS4 or general stormwater permit. Where a stormwater permit is located within an MS4, the load is assigned to the stormwater permit.

Table G2-9. MS4s in the Roanoke River watershed

MS4 permit holder	Permit number	Area (acres)
Roanoke County	VAR040022	28,907
City of Roanoke	VAR040004	23,577
Botetourt County	VAR040023	5,180
City of Salem	VAR040010	9,332
Town of Blacksburg	VAR040019	1,613
Town of Christiansburg	VAR040025	1,193

Legacy Sources

Legacy sources represented in the model are PCB contributions from contaminated streambed sediments and background atmospheric deposition of PCBs to surface waters. Those sources exist at an interface with the affected waterbody and can be characterized as nonpoint sources.

Contaminated Streambed Sediments

Streambed sediments can contain significant concentrations of PCBs from historical or current loadings or both. The PCBs can be released to the water column by resuspension of streambed sediments and desorption of PCBs, desorption of PCBs at the streambed-water column interface, and the direct diffusion of PCBs from lower contaminated sediment layers. The processes of adsorption/desorption and diffusion are discussed in Section G2.7.4, and a discussion of the in-stream processes of streambed sediment resuspension and deposition is presented in Section G2.7.3.

The mass of PCBs in streambed sediments available for loading at the beginning of the simulation period is set as an initial condition in the LSPC model setup. It is defined by a sediment tPCBs concentration and streambed depth, density, and porosity assigned to each model-represented stream class. The Roanoke River basin model includes an individual stream class for each model subbasin-representative stream reach, as discussed in Section G2.2.3. Stream classes define critical in-stream parameters including initial sediment pollutant concentration, streambed depth, density, and porosity. Assigning individual stream classes to each subwatershed stream reach allows model parameters to be specific to each reach.

The streambed sediment PCB concentrations for each model stream class were initially estimated as the mean concentration from the data record for monitoring stations within its associated subwatershed. In some cases, the data were adjusted slightly during the water quality calibration (see Section G2.7.4). Streambed depths were estimated as a function of the average modeled shear stress in each subwatershed stream reach. Higher shear stresses are a function of increasing channel slope and decreasing cross-sectional area. Stream reaches with higher shear stress values were assigned shallower streambed depths. The initial sediment PCB concentrations and streambed depths assigned to each reach class and associated subwatershed stream reach are presented in Appendix D.

Background Atmospheric Deposition

The net exchange of gas-phase molecules between the atmosphere and a waterbody (dry atmospheric deposition) is a function of the relative concentrations of the chemical in each. There are no available data to characterize the atmospheric and water column concentrations of gaseous PCBs in the Roanoke River watershed. The Chesapeake Bay Program Atmospheric Deposition Study (Chesapeake Bay Program 1999) has estimated a net dry atmospheric deposition rate for urban and regional (nonurban) areas, 16.3 and 1.6 µg/m^2/yr tPCBs, respectively (ICPRB 2007). The regional atmospheric deposition rate for tPCBs was incorporated into the Roanoke model as an estimate of local conditions. If local data become available, they will be incorporated into future TMDL studies.

G2.4. Model Boundary Condition

The Roanoke River watershed was divided into two separate segments for modeling purposes—the upper Roanoke, which extends from the River headwaters downstream to Niagra Dam, and the lower Roanoke (Staunton), which includes the length of the River from Leesville Dam to its confluence with the Dan River. Because there is no dynamic link between the two, to accurately represent the lower watershed, discharge data for the Leesville Dam, which represents all upstream flows to that point on the river, were incorporated as a model boundary condition.

To account for the PCB loadings from sources in the upper and middle Roanoke, a boundary condition PCB water concentration was assigned to the model-represented Leesville Dam discharge. The boundary water column concentration was estimated from available fish tissue data collected at monitoring station ROA140.66—which is the only monitoring station in Leesville Reservoir—using calculated bioaccumulation factors (BAFs) for resident fish species. A BAF-converted fish tissue PCB concentration is an estimate of the ambient water quality that captures all upstream source contributions and associated watershed and in-stream processes.

Four fish tissue records were converted into equivalent water column concentrations, giving a concentration range of 40.0–120.0 pg/L and a median concentration of 79.0 pg/L. The median value was assigned as the model boundary condition. That value is significantly lower than the applicable state human health water quality criterion for PCBs (1,700 pg/L) and is indicative of Leesville Reservoir's status as unimpaired for PCBs. Discussion of the methodology for developing and applicability of BAFs is presented in Appendix A.

G2.5. Model Assumptions

The major underlying assumptions associated with the Roanoke River model development are as follows:

- Bioaccumulation interactions between organisms are assumed to be negligible.
- The impact of sediment transport and siltation on channel geometry is not significant.
- No significant vertical stratification is assumed in the stream reaches.
- Each LSPC reach is assumed to be completely mixed for water quality parameters.
- The Chesapeake Bay Program regional net atmospheric deposition rate provides a reasonable estimate of volatilization and atmospheric deposition in the watershed.
- The decay rate of PCBs is assumed to be negligible.

G2.6. Model Limitations

The major limitations associated with the Roanoke River model are as follows:

- LSPC is a spatially lumped model and does not represent the spatial orientation of individual land uses within a subwatershed.
- Land uses and stream channel cross sections are fixed and constant throughout the modeling period.
- Stratification effects cannot be simulated because of representation as a completely mixed system. Lateral spatial gradients within the main channel or within tributaries cannot be represented.
- The model simulates the behavior of tPCBs representing overall behavior and trends. Variability in behavior that is seen at the congener/homolog level is generalized for a homolog grouping that is representative of the system.
- No explicit representation of organic carbon exists in the model. Organic carbon content of sediments is incorporated in the calculation of PCB partition coefficients
- The completely mixed system results in a single PCB dissolved phase; thus, model representation of streambed sediment and water interactions consist of only water column interactions (no pore water).

G2.7. Existing Conditions/Model Calibration and Validation

The model was developed in a step-wise manner, beginning with basic watershed processes and building on them to ultimately represent tPCB loading and transport. The foundation of the model is simulated hydrology. On the basis of the calibrated hydrology, sediment loading and transport were simulated and calibrated. Watershed hydrology and sediment simulations provide the framework for PCB loadings and transport modeling. The sections that follow discuss the development of each aspect of the watershed model.

G2.7.1. Selecting a Representative Modeling Period

Selecting a representative modeling period was done using the availability of stream flow and water, fish tissue, and sediment monitoring data collected in the Roanoke River watershed that cover varying wet and dry periods. VADEQ has collected water, fish tissue, and sediment monitoring data for the Roanoke River since 1973, but the period of 1990–2008 was selected for modeling purposes. That period includes monitoring results in step with modern analytical methods and includes varying climatic and hydrologic conditions, including dry, average, and wet periods that typically occur in the area.

G2.7.2. Hydrology

Hydrology and water quality calibration are performed in sequence, because water quality modeling is dependent on an accurate hydrology simulation. The driver of model hydrology is climatological data, described in Section G2.2.1. Such data are used as input to simulate the watershed water balance within the LSPC model framework that describes the watershed subbasin network, topology, land use, soils, and reach characteristics.

Hydrology Representation

The LSPC PWATER (water budget simulation for pervious land segments) and IWATER (water budget simulation for impervious land segments) modules, which are identical to those in HSPF, were used to represent hydrology for all pervious and impervious land units (Bicknell et al. 1997). Designation of key hydrologic parameters in the PWATER and IWATER modules of LSPC was required. Such parameters are associated with infiltration, groundwater flow, and overland flow.

Water Withdrawals

The Western Virginia Water Authority Water Pollution Control Plant (WVWAWPCP) (NPDES ID VA0025020), also known as the Roanoke City Regional Water Pollution Control Plant and the Roanoke City Wastewater Treatment Plant (WWTP), represents a large, continuous discharge to the mainstem of the Roanoke River in the upper model segment. The facility processes wastewater collected by the municipal sewer system serving the city of Roanoke and parts of Salem and Roanoke County. Data obtained from VADEQ's Water Supply Planning Program (WSP) indicates that seven surface water withdrawals in the upper segment provide water for municipal use in the sewer service area. Those withdrawals are represented in the model according to time series obtained from WSP to account for the discharge coming from the WVWAWPCP, balancing the water budget for the area. Major surface water withdrawals in the lower Roanoke (Staunton) segment are also represented in the model. Surface water withdrawals represented in the upper and lower model segments are presented in Table G2-10.

Table G2-10. Model surface water withdrawals

Owner	System	Source	Average withdrawal (cfs)	Model segment
Altavista, town of	Altavista	Mcminnis Spring	0.48	Lower
Altavista, town of	Altavista	Reed Creek	0.32	Lower
Altavista, town of	Altavista	Reynolds Spring	0.40	Lower
Altavista, town of	Altavista	Roanoke River	1.86	Lower
Bedford, city of	Bedford, City	Big Otter River	0.05	Lower
Bedford, city of	Bedford, City	Stoney Creek Reservoir	1.77	Lower
Brookneal, town of	Brookneal	Phelps Creek Reservoir	0.22	Lower
Campbell County USA	Central System Service Area	Big Otter River	2.24	Lower

Owner	System	Source	Average withdrawal (cfs)	Model segment
Dan River, Inc	Brookneal Plant	Falling River	1.43	Lower
Furniture Brands International	Altavista Plant	Roanoke River	2.36	Lower
ITG/Burlington Industries Inc	Hurt Plant	Roanoke River	0.41	Lower
ITG/Burlington Industries Inc	Hurt Plant	Sycamore Creek	4.43	Lower
Salem, city of	Salem WTP	Roanoke River	5.43	Upper
Salem, city of	Salem WTP	Roanoke River-Salem old WTP 1	4.81	Upper
Western VA Water Authority	Roanoke, City	Beaver Creek Res - Falling Creek	0.93	Upper
Western VA Water Authority	Roanoke, City	Crystal Spring	5.06	Upper
Western VA Water Authority	Roanoke, City	Carvins Cove Reservoir	20.48	Upper
Western VA Water Authority	Spring Hollow Reservoir	from Roanoke River	14.23	Upper

Surface water withdrawals, on average, account for 64 percent of the volume being discharged from the WVWAWPCP (Figure G2-6). Though the WVWAWPCP is a dedicated sewer system, after discussion with VADEQ and reviewing available discharge records, it was concluded that a significant volume of rainwater runoff makes its way into the system through inflow and infiltration. For purposes of model representation, it was assumed that the difference in withdrawal and WVWAWPCP discharge volumes are due to the inflow and infiltration of stormwater into the sewer system. To represent this process, the volume difference between withdrawals and WVWAWPCP discharge was represented as a withdrawal evenly distributed to all model subwatersheds draining the cities of Salem and Roanoke.

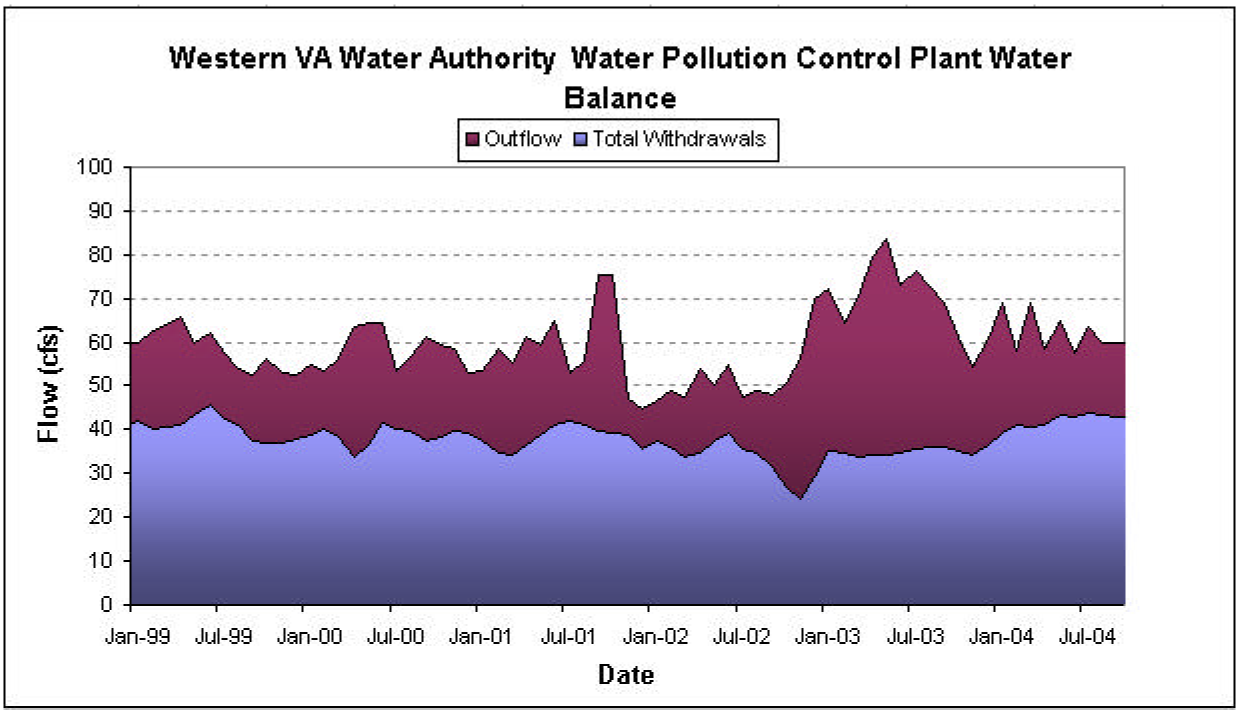

Figure G2-6. Western Virginia Water Authority Water Pollution Control Plant water balance.

Hydrology Calibration/Validation

Land use-specific hydrology parameters are used to calibrate modeled hydrology. Calibration involves a comparison of the modeled and observed flow rates at locations in the watershed where observed data are available. Appendix D presents LSPC Hydrology parameters and the range of values used for the Roanoke River watershed model.

STATSGO served as a starting point for designating infiltration and groundwater flow parameters. Starting values were refined through the hydrologic calibration process. As discussed in Section G2.2.2, a custom land use data layer was developed that accounts for the variability of hydrologic characteristics throughout the watershed. To account for topography variability in the upper and lower Roanoke (Staunton), two groups of land use parameters were configured in the model. This allows for the designation of separate hydrology parameter values for the upper and lower segments. Assigning appropriate parameter values was dependent on the composite hydrologic soil group/land cover distribution of each subwatershed.

Average daily flow discharge data were available for eight and seven USGS gages in the upper and lower Roanoke (Staunton) River, respectively (Figure G2-7). The upper Roanoke watershed model was calibrated using daily stream flow data from USGS gages 02056000 and 02053800, while the lower Roanoke (Staunton) was calibrated using gages 02066000 and 02061500. USGS gages 02056000 and 02066000 were selected as calibration points because they represent the farthest downstream locations in the upper and lower sections and capture the distribution of land uses and soil groups in each. An accurate model calibration at those points would capture the overall water budget for the upper and lower Roanoke (Staunton) and reflect the cumulative range of flows for their entire stream networks.

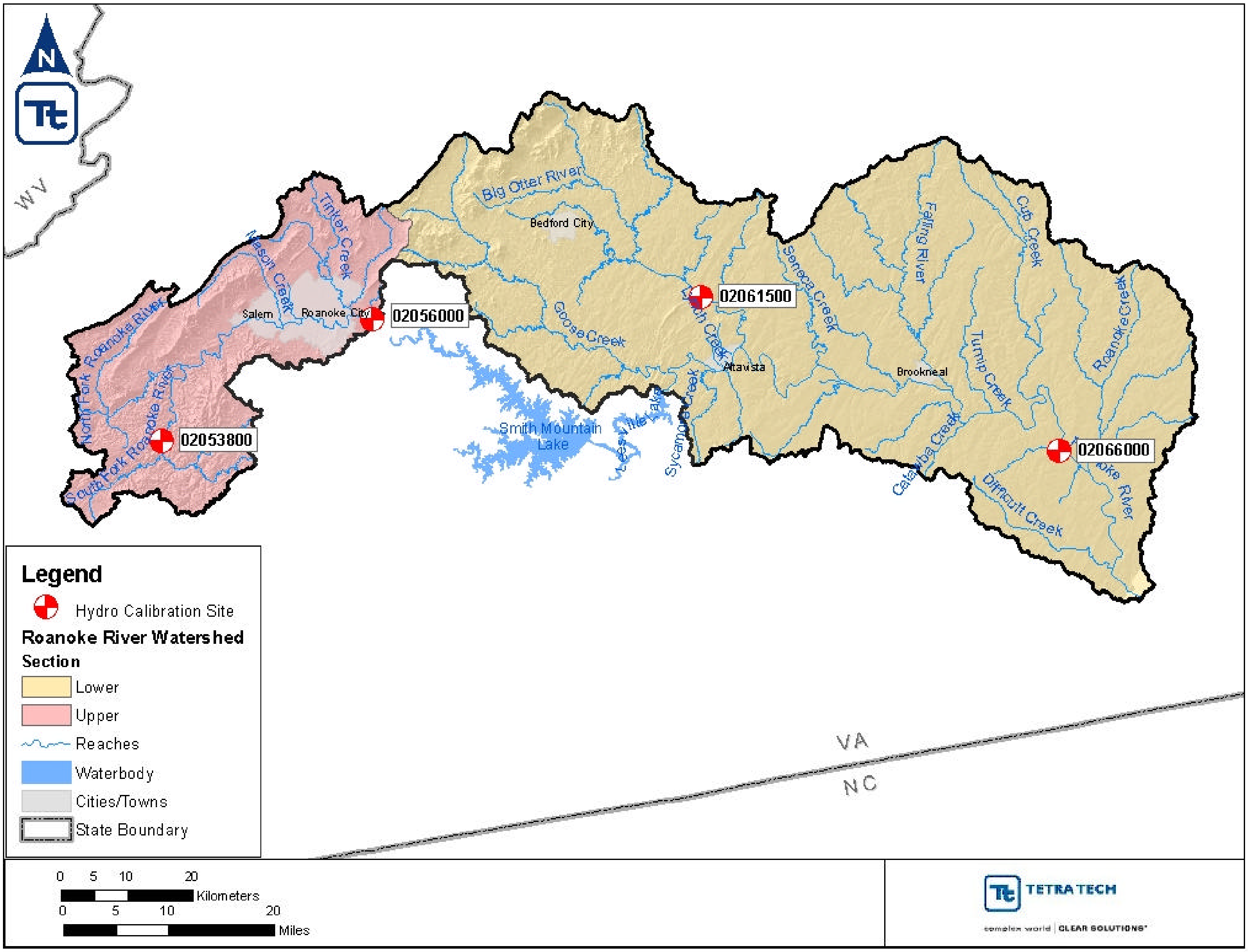

Figure G2-7. Locations of hydrology calibration USGS gages.

USGS gages 02053800 and 02061500 are on tributaries to the upper and lower Roanoke (Staunton)—South Fork Roanoke River and Big Otter River, respectively—and were used as calibration points to verify the applicability of the calibration to smaller areas within watersheds. Agreement between simulated and observed flows at both mainstem and tributary points would suggest an accurate hydrologic system representation of the upper and lower Roanoke (Staunton) watersheds. The USGS gages used for calibration are listed in Table G2-11.

Table G2-11. USGS continuous daily discharge gages used for hydrology calibration

Site ID	Station name	Drainage area (square miles)	Period of record
02053800	South Fork Roanoke River near Shawsville, VA	109	1/1/1990–5/31/2008
02056000	Roanoke River at Niagra, VA	509	1/1/1990–5/31/2008
02061500	Big Otter River near Evington, VA	315	1/1/1990–5/31/2008
02066000	Roanoke (Staunton) River at Randolph, VA	2,966	1/1/1990–5/31/2008

Model calibration years were selected using the following four criteria:

1. Completeness of the weather data available for the selected period
2. Representation of low-flow, average-flow, and high-flow water years
3. Consistency of selected period with key model inputs (i.e., land use coverage)
4. Quality of initial modeled versus observed data correlation

After a review of the data for these four selection criteria, the years 2004 and 1996 were chosen as calibration periods for the upper and lower Roanoke (Staunton), respectively. The NLCD land use coverage used in the model was developed in 2001; therefore, the selected calibration periods are consistent with that key model input. The model was validated for long-term and seasonal representation of hydrologic trends using a period of 18.5 years (January 1, 1991, through May 31, 2008) for both the upper and lower watersheds.

Model calibration was performed using the error statistics criteria specified in HSPEXP, temporal comparisons, and comparisons of seasonal, high flows, and low flows. Calibration involved adjusting infiltration, subsurface storage, evapotranspiration, surface runoff, and interception storage parameters. After adjusting the appropriate parameters within acceptable ranges, good correlations were found between model results and observed data. Hydrology calibration and validation results are presented in Appendix E. It is important to note that although the included log plots allow for comparative visualization of flows that span several orders of magnitude, that type of graph tends to diminish the differences in high flows, while exaggerating the differences in low flows.

Overall, the calibrated model predicted the watershed water budget well. All model validations showed the modeled water budget to be within 9 percent of observed conditions. Predicted seasonal volumes were also within recommended ranges at every location. Predicted storm volumes and storm peaks also closely matched observed data. Because the runoff and resulting stream flow are highly dependent on rainfall, occasional storms were over-predicted or under-predicted depending on the spatial variability of the meteorological and gage stations.

G2.7.3. Sediment

In-stream sediment concentrations are modeled as a function of discrete processes including erosion of soil particles from land areas, transport of eroded sediments to streams, and in-stream transport, scour, and deposition of sediments. Sediment loadings are dependent on hydrologic conditions, particularly the amount and timing of surface runoff, while in-stream processes are dependent on the unique hydraulics of each reach.

Sediment Representation

Land Loads

Sediment erosion from pervious land areas is represented as the net mass of soil particles detached from the land surface by rainfall and transported by overland flow. Sediment loadings to streams are estimated by land use category and are represented as the sum of three particle size fractions (sand, silt, and clay). Model parameters are closely related to the factors of the USLE (Wischmeier and Smith 1978). On impervious surfaces, sediment loadings are determined by an estimated rate of soil particle accumulation. In addition to sediment loadings simulated as the result of soil detachment, LSPC allows for the specification of fixed event mean concentrations.

Point Sources

In the Roanoke River watershed, 52 facilities representing 55 outfalls are permitted for discharging TSS loads. TSS discharges from point sources are assumed to be composed entirely of silt. For a discussion of the model representation of such sources, see Section G2.3.1.

In-stream Processes

The in-stream processes of deposition, scour, and transport determine how sediment loadings are translated to water column sediment concentrations (TSS). In-stream sediment dynamics are dependent on the hydraulic characteristics of a stream reach, which are represented by an FTABLE that defines the relationships among stage (depth), storage (volume), surface area, and discharge. Model FTABLEs are automatically generated by LSPC as a function of stream channel cross sections. As discussed in Section G2.2.3, model stream channel cross sections were estimated as function of drainage area. To date, no field measurements of channel cross sections have been made for streams in the Roanoke River basin with which to verify estimates.

Streambed deposition, scour, and sediment transport for silt and clay are determined by adjustable critical shear stress values. Two shear stress parameters, one for scour and one for deposition, establish a range above and below which scour and deposition occur, respectively. If the shear stress resulting from stream velocity is within the established range, sediment transport occurs (Figure G2-8). In-stream deposition, scour, and transport of sand are determined by the average stream flow velocity. For a given velocity, sand transport capacity is established, and scour and deposition occur when in-stream concentrations are below and above capacity, respectively. Note that although scour and resuspension alter the depth of the streambed throughout the simulation period, the initial channel cross section is assumed to be fixed.

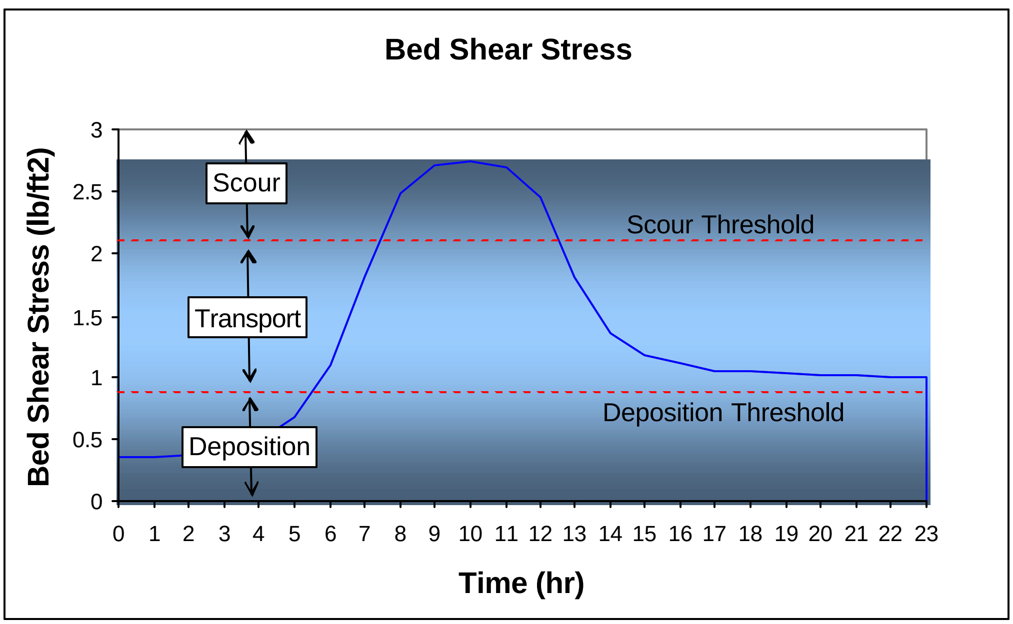

Figure G2-8. Model representation of in-stream cohesive particle dynamics.

Because no stream reach cross-section data were available at the time of TMDL development, the model generated FTABLEs were assumed to reasonably represent field conditions. To maintain a hydrologic regime where high- and low-flow events are associated with streambed scour and deposition, respectively, individual stream classes were assigned to each subwatershed stream reach as discussed in

Section G2.2.3. Stream classes define critical in-stream parameters including the critical stress thresholds that determine the occurrence of streambed scour and deposition.

Sediment Calibration

Land use and stream class specific sediment parameters are used to calibrate modeled sediment loading and in-stream processes, respectively. Calibration involves comparing the modeled and observed sediment loads and TSS concentrations at locations in the watershed where observed data are available. Appendix D presents LSPC sediment parameters and the range of values used for the Roanoke River watershed model.

Sediment land use parameters are closely related to the factors of the USLE (Wischmeier and Smith 1978), which served as a starting point for designating related soil detachment and washoff parameters. Appropriate values were assigned to the composite land use on the basis of the land cover description and hydrologic soil group. Starting values were refined through the sediment calibration process. Event mean concentrations were also defined to represent background concentrations not captured by the discrete erosive processes simulated by the model, particularly for low-flow conditions. All sediments and soils represented in the model are assigned particle class fractions (e.g. % sand, silt, clay). Analysis of the distribution of STATSGO soil groups in the watershed was used to estimate the particle class fractions of eroded upland soils.

In-stream sediment parameters are based primarily on the physical properties of the particle class fractions including particle diameter, fall velocity, and density. Such properties were estimated from the range of literature values presented in *EPA BASINS Technical Note 8, Sediment Parameter and Calibration Guidance for HSPF* (USEPA 2006). Streambed volume and porosity are parameters describing physical properties that represent the streambed as a whole. Streambed volume was estimated as described in Section G2.3.2, and streambed porosity was estimated on the basis of the literature source mentioned above. VADEQ monitoring data was used to estimate the particle class composition of the streambed for each model stream class.

As described above, a unique stream class was assigned to each subwatershed stream reach, which allowed individual in-stream parameters to be designated for each, including critical stress thresholds and streambed characteristics. This allowed for the representation of a consistent hydrologic regime where high- and low-flow events are associated with streambed scour and deposition, respectively. Shear stress thresholds for scour were designated for each subwatershed as the modeled 70th percentile shear stress value. Because of the free-flowing nature of the modeled segments, shear stress values for deposition were set to values simulated in subwatersheds where deposition is likely to occur, including near impoundments. Such a simplification of field conditions was necessary in lieu of available monitoring data verifying stream channel cross-section geometry. If the data become available, they can be incorporated in future TMDL studies.

Observed TSS data are available for 21 and 43 monitoring stations in the upper and lower Roanoke (Staunton), respectively. On the basis of the number of data records and co-location with USGS continuous flow gages, the Roanoke River watershed model was calibrated for sediment using TSS monitoring stations ROA227.42, ROA204.76, ROA97.46, and ROA67.91 (Figure G2-9). Stations at river mile 227.42 and 204.76 are in the upper Roanoke model segment, while stations at river mile 97.46 and 67.91 are in the lower Roanoke (Staunton) model segment. General descriptions of those monitoring locations are presented in Table G2-12.

Table G2-12. TSS monitoring station used for TSS calibration

Station ID	Station description	Period of record	Associated flow gage
4AROA067.91	Rt.746 bridge (Watkins Bridge) near Randolph, VA	2/1/1990–9/10/2007	USGS 02066000
4AROA097.46	Roanoke River at Brookneal gage, Rt. 50	1/24/1990–5/1/2007	USGS 02062500
4AROA204.76	Roanoke River at Roanoke City, VA	10/13/2005–11/22/2005	USGS 02055000
4AROA227.42	Rt. 773 at gaging station in Lafayette, VA	1/10/1990–5/9/2007	USGS 02054500

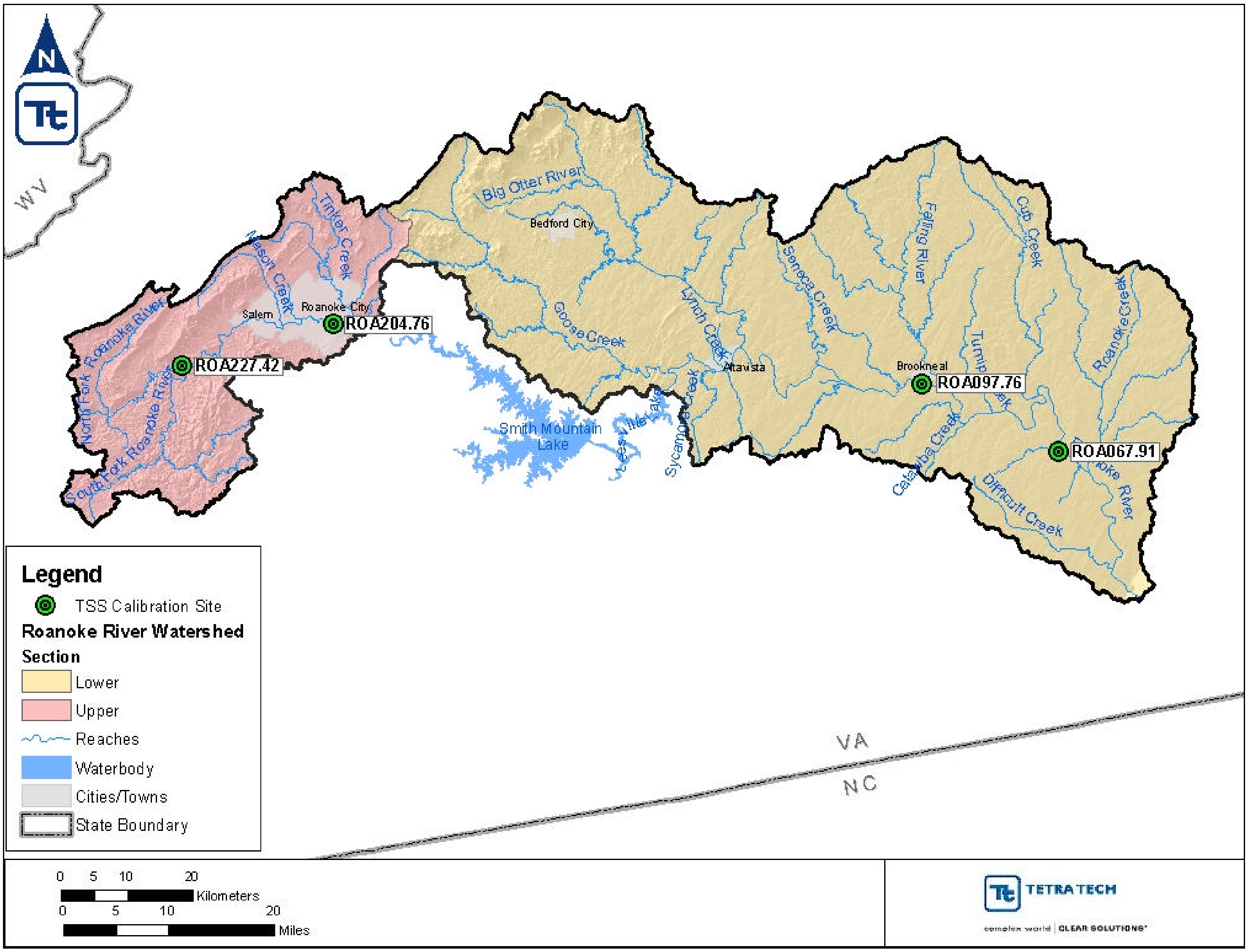

Figure G2-9. Locations of TSS monitoring calibration stations.

Sediment simulations were run for the model time series as described in Section G2.7.1. Antilog plots of flow versus sediment loads for observed and modeled data are presented in Appendix F for the selected calibration locations. In general, the magnitude of sediment loadings for observed and modeled data increase at a similar rate and are within the same range for the gradient of flow conditions. Observed loadings are, generally, more variable in relation to flow conditions than in modeled scenarios. Log plots comparing model output to observed TSS concentrations at the selected locations are also presented in

Appendix F. Note that observed concentrations reported as detection limits have been assigned a concentration of 3 mg/L.

G2.7.4. PCBs

LSPC was configured to simulate tPCBs in both the dissolved- and sediment-associated states to characterize water quality conditions in the Roanoke River watershed. The simulation of loadings and in-stream behavior of tPCBs as a sediment-associated pollutant is dependent on the hydrologic and TSS calibrations that serve as its foundations.

The model was set up to represent a unique stream class for each subwatershed stream reach as discussed in Section G2.2.3. Each model stream class defines critical in-stream parameters, including the conditions related to the mass balance of PCBs for the sediment-water system in each stream reach. PCBs are partitioned into dissolved and particulate fractions in both the water (PCB with suspended sediment interaction) and sediment layers (PCB with bed sediment interaction). LSPC simulates deposition (settling) and scour (resuspension) of PCBs with sediment, in addition to sorption/desorption and in-stream losses.

PCB Representation

The LSPC model was configured to simulate PCBs in both the dissolved- and sediment-associated states. PCBs typically adsorb to sediment particles, which are transported into streams and rivers through erosion. Simulation of a pollutant as sediment-associated, therefore, requires that land loadings be tied to eroded soils. Once in-stream, the pollutant is partitioned into dissolved- and sediment-associated states. While sediment-associated, in-stream transport, accumulation, and attenuation of PCBs are subject to the processes of in-stream transport, deposition, and resuspension that characterize the movement of sediments. Dissolved PCB concentrations are defined by a partition coefficient that specifies the equilibrium concentration of PCBs in the water and on sediments. In LSPC, movement of PCBs between the dissolved- and sediment-associated states occurs solely as adsorption and desorption, which approaches equilibrium as defined by the partition coefficient and adsorption/desorption rate.

Partitioning Coefficient

A sediment partition coefficient (K_d) describes the tendency of a pollutant to exist in the dissolved state in an aqueous environment. The greater the K_d value, the less tendency the pollutant has to be dissolved. K_d is estimated for PCBs as a function of the PCB octanol-water partition coefficient (K_{ow}) and the organic carbon content of the sediments (f_{oc}) (Karickhoff et al. 1979). K_{ow} varies for different PCB homologs and increases with increased chlorination. The sediment partition coefficient is calculated as follows:

$$K_d = 1 \times 10^{-6} \times f_{\mathrm{oc}} \times K_{\mathrm{ow}}$$

where

K_d = the distribution coefficient between dissolved- and sediment-associated state (L/mg)
f_{oc} = weight fraction of the total carbon in the solid matter (gC/g)
K_{ow} = octanol-water partition coefficient ($ug/L_{octanol}/ug/L_{water}$)

Simulation of Adsorption/Desorption

LSPC uses the equation developed by Onishi and Wise (1979) that describes the transfer of a chemical between the dissolved and adsorbed (sediment-associated) state on sediment type J. LSPC represents three particle classes (sand, silt, and clay) for suspended and streambed sediments giving six J sediment types.

$$\frac{d(RESDJ \times SQALJ)}{dt} = RESDJ \times KJT \times (K_d \times DQAL - SQALJ)$$

where

RSEDJ = total quantity of sediment type J in the stream (mg)
SQALJ = concentration of pollutant on sediment type J (mg/mg)
DQAL = concentration of dissolved pollutant (mg/L)
KJT = temperature corrected transfer rate between dissolved state and sediment type J

Thus, adsorption of a pollutant by sediment or desorption from sediment is assumed to occur toward an equilibrium condition with transfer rate KJT if the particulate pollutant concentration differs from its equilibrium value (Bicknell et al. 1997). The conservation of mass is in the stream is, therefore, described as follows:

$$\sum_{j=1}^{6}(RSEDJ \times SQALJ) + (VOL \times DQAL) = TOT$$

where

VOL = volume of water in the stream
TOT = total quantity of pollutant in the stream

Total PCBs

The model was set up to represent PCBs in the watershed as tPCBs, or the sum of all possible 209 congeners. This simplification required that congener-specific PCB properties (K_d and KJT) be generalized for model representation. K_d and KJT are defined in the model for both suspended and bed sediments. Available congener data was analyzed to determine dominant homolog groups, which were used to define the K_d and KJT parameters as described in the PCBs Calibration section.

PCB Calibration

Land use and stream class specific PCB parameters are used to calibrate modeled PCB loading and in-stream processes, respectively. Calibration involves a comparison of the modeled and observed PCB concentrations at locations in the watershed where observed data are available. Appendix D presents LSPC PCB parameters and the range of values used for the Roanoke River watershed model.

Land use parameters define the PCB potency factors of the individual model land uses. Developing and applying land use potency factors is described in Section G2.3.2.

Monitoring data collected by VADEQ were used to define the model's design and representation of critical parameters required for simulating PCBs in each stream class. Such parameters include the following:

- Particle class fractions of upland soils and streambed sediments
- The initial tPCBs concentration of particle class fractions
- Partition coefficients as a function of the fraction of the organic carbon content in stream sediments and homolog composition of PCB contamination
- Adsorption/desorption rates as a function of the homolog composition of PCB contaminated suspended sediments

Particle Class Fractions

Particle class fractions of upland soils and streambed sediments were estimated as described in Section G2.7.3.

Initial Total PCBs Concentration in Particle Class Fractions

The initial tPCBs concentrations of upland soils were estimated as described in Section G2.3.2. This concentration was assumed to be evenly distributed throughout the three particle class fractions. PCBs' affinity for non-polar media is activated when in a polar (aqueous) environment. The organic carbon content of different particle classes in upland soils, therefore, has little or no effect on its distribution between them.

VADEQ monitoring data were used to estimate the particle class composition of the streambed in each model stream class as described in Section G2.7.3. On the basis of that estimated composition, the percent cohesive mass (e.g. silt + clay) was defined and used to assign a normalized tPCBs concentration to the cohesive fraction of streambed sediments using available whole sediment sample monitoring data. PCB sediment monitoring data was assigned to each stream class as described in Section G2.3.2. The sand fraction of streambed sediments was assumed to have a negligible PCB concentration. The sorption of PCBs to sediment in an aqueous environment is a function of organic carbon content. The organic carbon content of sand is assumed to be zero for the purposes of this TMDL study (Hamrick 2007). In addition, the difference in the organic carbon content of silt and clay is assumed to be negligible. PCBs, therefore, are not represented as having a greater affinity for either (see the discussion of developing partition coefficients).

Partition Coefficients

VADEQ sediment and water column PCB monitoring data included measures of total organic carbon (TOC) concentrations and tPCBs homolog composition. The data were used to develop partition coefficients for suspended and streambed sediment associated tPCBs. Note that the available TOC monitoring data are for whole samples and do not specify the organic content of individual particle classes. As a result, it was assumed that the organic content of sediments was evenly distributed throughout the cohesive fraction.

Individual partition coefficients were developed for bed sediment associated PCBs in each stream class, while watershed section specific (upper and lower) partition coefficients were developed for suspended sediment-associated PCBs. A distinction in the scale at which partition coefficients were developed was made because while streambed sediments tend to be relatively stationary, suspended sediments move rapidly through a stream system. Thus, variability in PCB homolog partitioning behavior is generalized at the subwatershed and watershed section scale for PCBs associated with streambed and suspended sediments, respectively.

Streambed sediment PCB homolog and organic carbon data were grouped by stream class to calculate partition coefficients for each. Partition coefficients were calculated as a function of the representative homolog and the average percent TOC, where a representative homolog is defined as the percent composition weighted average homolog. A representative homolog represents a hypothetical tPCBs homolog and is used to define the tPCBs K_{ow}. Stream classes for which there were no available TOC or homolog data were assigned median data set values. Suspended sediment-associated PCB partition coefficients were calculated similarly to those in streambed sediments, except water column homolog and organic carbon data were grouped by watershed section, and median values were used.

Adsorption/Desorption Rates

A range of adsorption/desorption rates for PCB homologs is presented in a study of PCB desorption in Hudson River sediments (Schneider 2005). Those rates were used to designate the adsorption/desorption rate for tPCBs on suspended sediments in the Roanoke River model. The median representative homologs from water column PCB monitoring data for the upper and lower Roanoke (Staunton) sections were used to define the representative rate for each. The adsorption/desorption rate for PCBs in streambed sediments was calibrated on the basis of observed low-flow water column PCB concentrations.

Observed water column PCB data are available for 29 monitoring stations throughout the Roanoke River watershed. The stations were sampled as part of the 2005–2008 PCB monitoring special study conducted by VADEQ (see Section 2.3 of *Roanoke River PCB TMDL Development*). On the basis of the confidence in the analytical results of the sampling data, the Roanoke River watershed model was calibrated at the 24 PCB monitoring stations shown in Figures G2-10 and G2-11. General descriptions of the monitoring locations are presented in Table G2-13.

Table G2-13. PCB monitoring stations used for PCB calibration

Monitoring station	Station description	Sample dates
4ADFF002.02	Difficult Creek at Rt. 716	8/28/07
4AROA059.12	Roanoke River near Rt. 360 - Clover	9/10/07, 10/26/07
4ABWC001.00	Black Walnut Creek	10/26/07
4AROC001.00	Roanoke Creek near Saxe	8/28/07, 10/26/07
4AROA067.91	Roanoke River near Rt. 746	9/10/07, 10/26/07
4ACUB002.21	Cub Creek at Rt. 649 (Coles Ferry Road)	8/28/07, 10/26/07
4AROA090.50	Roanoke River at Rt. 620 South of Brookneal	8/8/07, 10/26/07
4AROA097.76	Roanoke River upstream of Brookneal	8/8/07, 3/6/08
4AFRV002.78	Falling River downstream of lagoon outfall	9/10/07
4AROA108.09	Roanoke River near Long Island	9/10/07
4AROA124.59	Roanoke River downstream Altavista	3/10/08, 5/9/08
4AROA127.79	Roanoke River downstream of Altavista STP	8/9/07
4ABOR000.62	Big Otter River at Rt. 712	8/21/07, 10/26/07
4AXLN000.00	Unnamed trib on BGF property	12/1/07
4AROA129.55	Roanoke River near business Rt. 29 bridge at USGS gage	8/8/07, 10/26/07, 5/9/08
4ASCE000.26	Sycamore Creek near Pocket Road	8/27/07
4ALYH000.17	Lynch Creek at Riverside Park	5/9/08
4AROA131.55	Roanoke River at Rt. 29 Bridge bypass, Altavista	8/8/07, 5/9/08
4AGSE000.20	Goose Creek	9/10/07, 10/26/07
4AROA199.20	Roanoke River just upstream Niagra Dam	3/3/08, 4/7/08
4AROA204.76	Roanoke River at Walnut Ave. in Roanoke City	3/3/08, 4/7/08
4AROA207.08	Roanoke River at Memorial Bridge	3/3/08, 4/7/08
4AROA212.17	Roanoke River at Rt. 419 Bridge near Lewis Gale	3/3/08, 4/7/08
4AROA227.42	Roanoke River at Rt. 773 at gaging station in Lafayette	3/3/08, 4/7/08

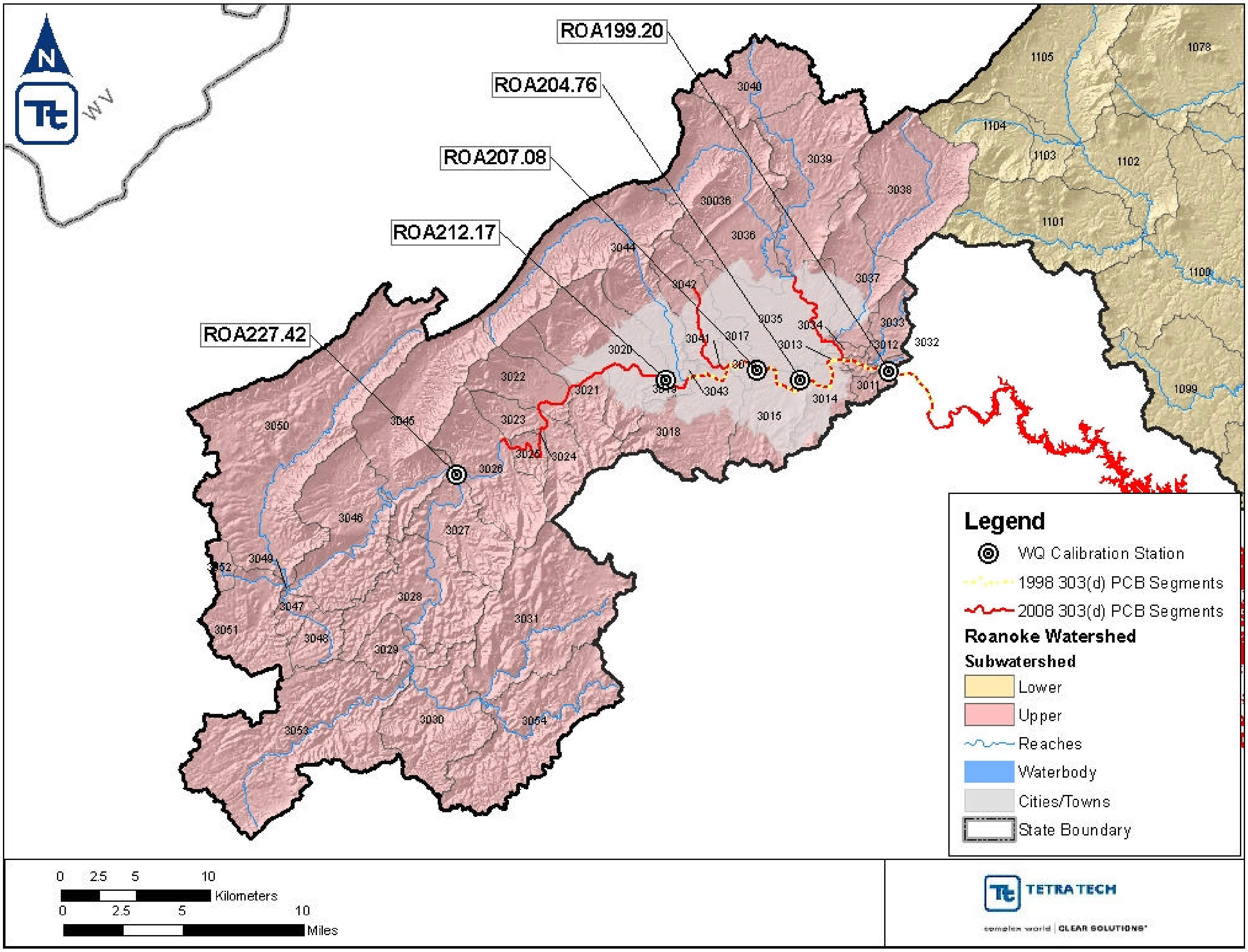

Figure G2-10. Locations of upper Roanoke PCB monitoring calibration stations.

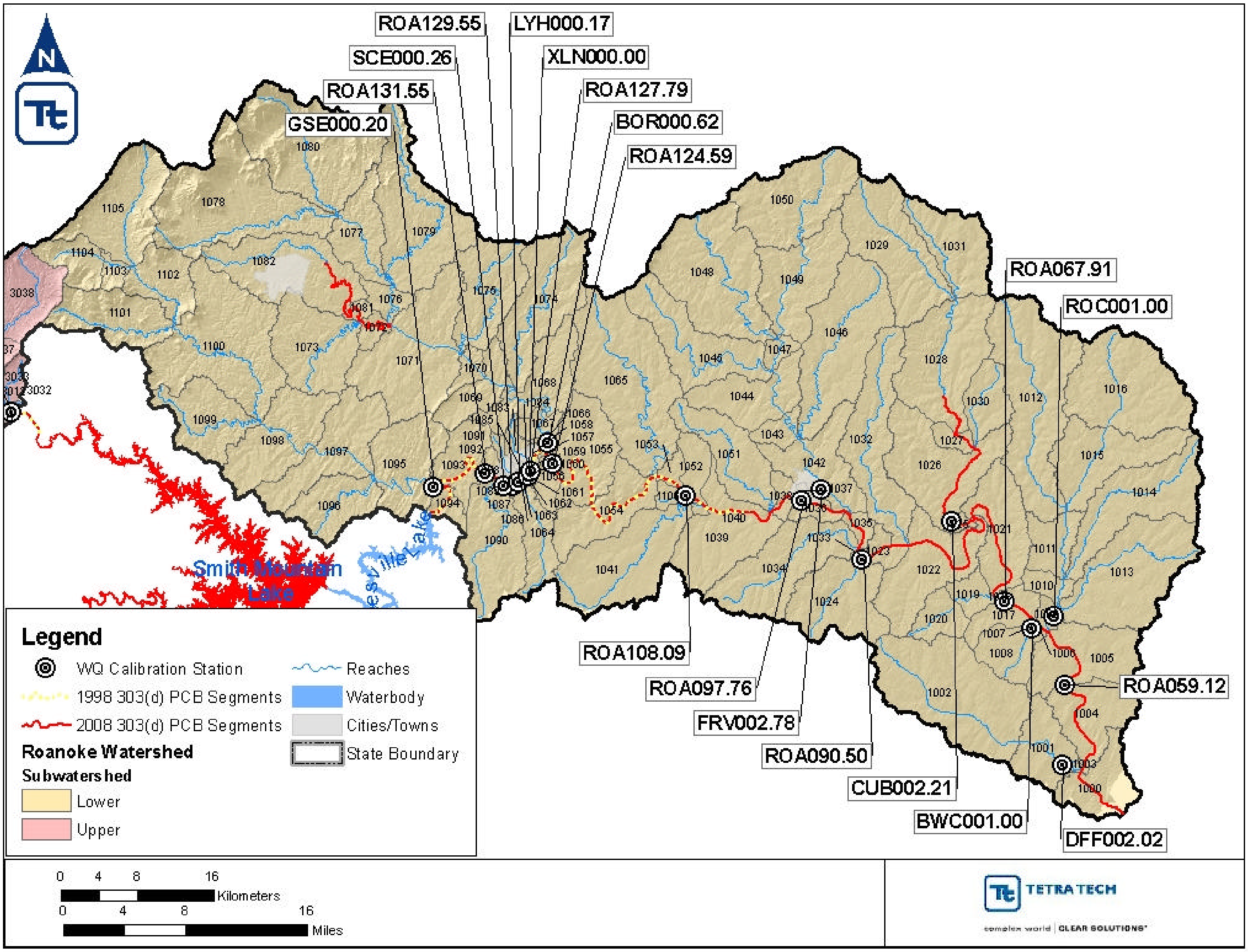

Figure G2-11. Locations of lower Roanoke (Staunton) PCB monitoring calibration stations.

PCB simulations were run for the model time series as described in Section G2.7.1. Log plots for observed and modeled tPCBs are presented at the selected calibration locations in Appendix F. In general, the model captures the trends and magnitude of contamination observed in the monitoring data.

At locations with significant upstream contaminated sources and high in-stream shear stresses, storm events cause in-stream concentration spikes as contaminated soils are transported to streams and contaminated streambed sediments are resuspended, releasing associated PCBs. In areas where there are few or no contaminated sites or streambed sediments, storm events cause in-stream tPCBs concentrations to decrease as clean inflows dilute the PCB concentrations directly fluxing from streambed sediments and atmospheric deposition. Finally, in areas where there are highly contaminated streambed sediments and relatively low in-stream shear stresses, the direct flux of PCBs from streambed sediments dominate water column concentrations, whereby storm events cause in-stream tPCBs concentrations to decrease even though there could be significant areas of upstream contaminated soil.

In addition, the magnitude of modeled low-flow and high-flow tPCBs concentrations are generally within the same magnitude as the observed data. This suggests that upland soils contamination areas and PCB concentrations, initial streambed sediment PCB concentrations, and water column-streambed sediment dynamics are being represented appropriately.

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